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TECHNICAL EVALUATION OF EMISSION CONTROL APPROACHES AND ECONOMICS OF EMISSION REDUCTION REQUIREMENTS FOR VEHICLES BETWEEN 6,000 AND 14,000 POUNDS GVW

CALSPAN CORPORATION

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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16. ABSTRACT

An account is presented of a two-part study concerned with the reduction of emissions from the group of vehicles populating the 6,000-14,000 pound GVW range. In the technical evaluation study, state-of-the-art control technology is utlized to synthesize control system strategies and to estimate their control effectiveness when applied to this class of vehicles. The economic analysis study develops the relationships between the different control strategies and the costs associated with their implementation. The following conclusions and recommendations are reported: (1) exhaust emissions (mass per mile basis) from late model MDV are principally weight dependent, increasing with weight; (2) a vehicle mix utilizing catalyst equipped conventional engines and pre-chamber type, turbocharged diesel engines with EGR provides the most effective control strategy for HC and CO emissions; (3) the above-cited control strategy also achieves the best fuel economy; and (4) a vehicle population comprised solely of conventional engines equipped with reducing catalysts achieves the most effective control over NO_x emissions. A description is given of a computer program developed to assess the impact on emissions and to evaluate implementation costs of the several control strategies. Numerical results are presented.

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Economic analysis	Gasoline engines	Emission reduction factors	
1973	Catalytic converters	Emission control strategies	
Motor trucks	Carbon monoxides		
Diesel engines	Nitrogen oxides		
Data	Exhaust emissions		
Evaluation	Cost comparison		
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Office of Mobile Source Air Pollution Control
Emission Control Technology Division
Ann Arbor, Michigan 48105

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FOREWORD

This report was prepared by Calspan Corporation, Buffalo, New York under Environmental Protection Agency (EPA) Contract No. 68-01-0463. The work was administered under the direction of the Office of Air Programs, Characterization and Control Development Branch, Division of Emission Control Technology, Mr. Robert E. Maxwell, Project Officer.

This is the project final technical report which describes and summarizes the results of studies conducted during the period from October 1972 through May 1973 and concerned with (A) technical evaluation of emission control approaches and (B) economics of emission reduction requirements for vehicles between 6,000 and 14,000 pounds GVW.

Part A effort was performed by the Vehicle Systems Department with the Part B studies conducted by the Operations Research Department. Acknowledgement is made of the contributions of D. T. Kunkel who assisted with the vehicle characterization task and G. M. Niesyty who participated in the economic analyses and C. Groenewoud who was responsible for writing the computer program.

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1.0 INTRODUCTION

This program was concerned with a research study devoted to a technical evaluation of emission control approaches and the economics of emission reduction requirements for vehicles with a gross vehicle weight (GVW) between 6,000 and 14,000 pounds. For convenience, this category of vehicles herein is referred to as medium duty vehicles (MDV).

The objective of the technical analysis was an evaluation of emission control approaches and reduction levels applicable to the MDV. A methodology was adopted that included: identification and characterization of vehicles in the MDV group, selection of representative 1973 model year vehicle/engine combinations and the determination of their baseline emission levels, selection of control techniques and alternative engine concepts providing emission reductions together with engineering estimates of the levels of these reductions and the identification of lead times and vehicle performance penalties associated with the different levels of emission reduction considered feasible. The assumption was made that the extensive control technology in existence for light duty vehicles (LDV) could be effectively adapted to the MDV.

A succinct account of the technical analysis study is included in Section II of this summary.

Relationships among the various reduction levels possible and their implementation costs for representative MDV vehicle/engine combinations were developed and analyzed under the economic analysis portion of the project. Estimated sticker prices for the selected emission control approaches were estimated together with related maintenance costs and combined into overall costs which include incremental fuel costs. These costs are then related to the emission reduction effectiveness of the different control strategies to determine the cost effectiveness of each.

Section III of this summary is a concise account of the results of the economic study.

2.0 PART A. TECHNICAL ANALYSIS

1. Summary, Conclusions and Recommendations

Medium duty vehicles are fitted with engine and drivetrain components often identical to, or derivatives of, those used in light duty vehicles. The MDV category is dominated in population by the pickup-type truck whose dual-purpose function imparts to this weight category, a usage and operating character not unlike the LDV category. Motor homes, with an appreciable share of current MDV annual sales, represent a unique exception.

Eight emission control systems are postulated for the MDV category. These systems are derived from technology developed for the LDV group and the projected reduction factors, fuel penalties and vehicle performance effects are estimated with reference to test data from light duty vehicles. Three categories of control approaches were formulated: catalytic converter, thermal reactor and fuel control (carburetion/induction). These are generic designations and other control devices are included in the implementation strategies for each.

Using an equivalent 1975 CVS-CH Federal Test Procedure, baseline emission data are determined from a sample of late model MDV and show that vehicle weight is the principal factor influencing emissions.

Computer simulation is employed to predict emission reductions and associated fuel penalties in implementing different control strategies derived from a combination of control approaches and alternative engines with lead times estimated for each. This analysis does not incorporate any effects of durability of control systems on emissions.

Subject to the qualifications noted in the report, the following conclusions and recommendations are appropriate:

- Exhaust emissions (mass per mile basis) from late model MDV are principally weight dependent, increasing with weight.
- A vehicle mix utilizing catalyst equipped conventional engines and pre-chamber type, turbocharged diesel engines with EGR provides the most effective control strategy for HC and CO emissions.
- The above-cited control strategy also achieves the best fuel economy.
- A vehicle population comprised solely of conventional engines equipped with reducing catalysts achieves the most effective control over NO_x emissions.
- It is recommended that emission standards for medium duty trucks apply to a GVW range bounded by 6,000 and 10,000 lb. limits.

2. Supporting Discussion

a. Methodology

The technical approach employed in meeting the program objectives was consistent with explicit procedural details specified by EPA in the statement of work. Task-type items, requiring continual review and updating throughout the project, are discussed below.

An initial task required identifying the vehicle types comprising the 6,000-14,000 lb. GVW category according to sales, ranges of GVW, engines, drivetrains, usage and other identifying characteristics. From these data vehicle groups were formed to aid in validating appropriate GVW limits for the MDV. For each such group, a representative vehicle/engine/drivetrain was selected, the current model year emission controls specified and baseline emissions determined. Emission data, measured according to an equivalent 1975 Federal Test Procedure, were supplied by EPA. The group-representative approach proved fruitless as the available emissions data for MDV did permit discrimination among any of the vehicle/engine/drivetrain combinations selected. Rather, the principal disciminant factor found was vehicle test, or inertia, weight.

Using emission control technology from the light duty vehicle field, likely control systems were formulated for the MDV category with estimates made for each of reduction factors, vehicle performance penalties and implementation lead times. A computer program was developed to calculate annual mass emissions and costs associated with implementing the individual control strategies in medium duty vehicles.

b. Vehicle Characterization

As indicated above, the planned procedure involved the grouping of MDV vehicles on the basis of data on usage, sales and vehicle physical characteristics. Such usage factors as load weight, trips per day, daily mileage, route followed, etc. were felt to significantly affect emissions. Usage data of this type were generally very sketchy, out of date and often completely nonexistent or inapplicable. Consequently, vehicle groups were formed using judgment and practical considerations based on the limited data available. The resultant grouping is shown in the table below.

Vehicle Grouping

Group	Body Style or Type
Pickup/Camper	Pickup Camper Special
Van/Passenger Van	Van Passenger Van
Multi-Stop Van	Multi-Stop Van
Chassis	Cab Chassis Cowl Chassis Bare Chassis
Motor Home Chassis	Motor Home Chassis

Manufacturers' data on vehicle engines, transmissions and axle ratios for the different models were collected for the 1973 model year MDV. A summary of these data, arranged according to the vehicle groupings selected, appears in Table 2.2 of the report (page 2-12). A number of significant facts emerge from this compilation. First, all vehicles in the pickup/camper and van/passenger van groups have GVW specifications within the range from 6,000 to 10,000 lbs. Second, all models of the other three groups (except for a single, isolated model) have GVW specifications either between 6,000 to 10,000 lbs. or 10,000 lbs. and above (i.e., only one model overlaps the 10,000 lb. GVW level). Third, the data show that only one model also overlaps the 6,000 lb. GVW level. Therefore the 6,000 and 10,000 lb. GVW levels are distinct demarcation lines among vehicles with reference to GVW.

The same basic engine families are generally used in the LDV and MDV groups. Most MDV engines have direct light duty counterparts and, with few exceptions, are internally identical. Medium duty engines for the 1973 model year are equipped with fewer add-on emission control devices and rated at slightly higher horsepower levels than their LDV counterparts. Intermediate eight-cylinder engines (330-360 CID) are overwhelmingly popular for the MDV group with the 350 and 360 CID engines dominant. Six-cylinder engines are a minor factor. It therefore follows the horsepower-to-weight ratio will be lower for medium duty vehicles so that the engines will be operated at relatively higher loading than in the LDV.

Vehicle populations and population trends derived from sales data are important in establishing the impact on total pollutant emissions attributable to specific groups of vehicles. Using the conventional GVW groupings of the truck industry, sales data show that the 6,000-10,000 lb. group is by far the most populous if the LDV group ($<$ 6,000 lbs. GVW) is excluded. While this group has exhibited an unbroken trend of increased sales for the past decade, the sales of the 10,000-14,000 lb. GVW group have remained static at a much lower level during most of this period. A strong sales surge in this latter group, considered substantially attributable to motor home sales, has occurred since 1970 (Table 2.3, page 2-23 and

Table 2.4, page 2-24). The importance of the recreational vehicles (campers and motor homes) is highlighted by the estimate that they accounted for approximately 40% of the MDV sales* in 1972. On the other hand, the dominant popularity of the pickup truck is demonstrated by a share in excess of 55% of annual MDV sales* over a period of years.

As noted earlier, usage data on MDV are very limited and often not relevant to specific needs of this program. Specific deficiencies encountered are tabulated below:

- classification by inappropriate GVW ranges
- use of population samples not typical of the national distribution of vehicles
- obsolete information based on a nonexistent vehicle mix
- fragmentary information on daily usage by vehicle type

Analysis of the more pertinent data shows consensus that all truck types under 10,000 lbs. GVW (which includes light duty trucks as well) are urban oriented and act and operate in traffic much like a typical passenger automobile. These trucks are found to operate without load for approximately 30% of the time. Pickup-type vehicles and their variants, are used predominantly for nonwork related purposes. In general, the available usage data on vehicles in the 6,000-10,000 lb. and 10,000-14,000 lb. GVW ranges did not provide any basis for discriminating between the two in establishing weight limits for the MDV category.

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*In this context, the 6,000-14,000 lbs. GVW range.

c. Baseline Emissions

Emissions data for HC, CO and NO_x from over one hundred late model vehicles with a GVW between 6,000 and 14,000 lbs. were supplied by EPA. These data originated from three sources, an in-house EPA effort and two different EPA contractors. The test procedure employed was the basic 1975 CVS-CH Federal Test Procedure developed for the LDV with the only variations associated with the determination of vehicle inertia weight and road load horsepower. Inertia weight, rounded to the nearest 500 lbs., is obtained by the addition to vehicle curb weight of 500-lb. increments (maximum of 1,500 lbs.) according to a schedule based on payload capacity. Road load horsepower is given as a linear function of inertia weight, varying from 17.7 hp. at 5,000 lbs. to 65.8 hp. at 10,000 lbs. These procedural details do not necessarily represent the test procedures EPA may ultimately specify for the MDV category.

A review of these emissions data showed that: (a) a number of older models were included in the sampling (1965-1969), (b) some vehicles were tested in an "as received" condition while others were tested after the engine dwell, timing and idle speed were adjusted to specifications, (c) the bulk of the data was concentrated at an inertia weight of 5,000-5,500 lbs., (d) data at the higher inertia weights (8,000-10,000 lbs.) were primarily from motor homes, (e) some vehicles with very low mileage ("green engines") were sampled, (f) data were included on 1973 California vehicles which were equipped with EGR systems and (g) the data showed a wide scatter at any given inertia weight.

The scatter in the emissions data precluded any discrimination among different vehicle engine combinations. This finding does not imply, however, that such differences do not exist. A plot of the data as a function of inertia weight did show an increase of emissions with weight for each of the three pollutants.

A series of linear regressions were performed on various subsets of the data with mass emissions per mile regressed on inertia weight. Because of the poorly distributed inertia weights, it was necessary to use a data sample that included all 1970-1973 vehicles, both tuned and untuned, to extend the range of inertia weights encompassed. California vehicles and those with green engines were excluded. Results of this analysis on a sample size of 89 vehicles indicated that the inclusion of emissions data for only nine motor homes increased the slope of the regression lines significantly (compared to trucks-only data) for CO and NO_x emissions. Consequently, a regression analysis was made for only the truck data. Results are given below.

Regression Equations - Trucks Only (76 Points)

$$M_{HC} = 0.526\, I_w + 2.38$$

$$M_{CO} = 7.09\, I_w + 19.8$$

$$M_{NO_x} = 1.02\, I_w + 1.61$$

M_i = grams/mile of pollutant i

I_w = inertia weight, thousands of lbs.

Because of the small sample size and narrow inertia weight range available for motor homes, the emissions data were averaged.

Average Emissions - Motor Homes (9 Points)

HC	CO	NO_x	Mean Test Weight
gm/mi	gm/mi	gm/mi	lbs.
7.82	125.71	13.07	8,400

Subsequent to completion of work on this project, the Project Officer supplied emissions data on additional MDV as well as instructions for broadening the original data base and requested that a regression analysis be performed for the combined truck and motor home data. The resultant equations are listed below.

Regression Equations - Trucks and Motor Homes (135 Points)

$$M_{HC} = 0.555\, I_w + 1.94$$
$$M_{CO} = 11.20\, I_w - 8.19$$
$$M_{NO_x} = 1.35\, I_w - 0.56$$

These equations were generated after the completion of the project and were not used in the analysis.

d. Weight Limits

A choice of GVW limits was based on four factors associated with the vehicles included in the medium duty category; population, physical characteristics, usage and emissions. The motor home was readily isolated as a unique member of this group in terms of usage and emissions.

The selection of 6,000 lbs. GVW as a lower limit for the MDV category is clearly defensible. This GVW level has been shown to be a natural dividing line at which certain LDV models reach maximum weight ratings and many MDV models have minimum ratings. Such a line of demarcation is important in avoiding the necessity of certification of given vehicle models by two different procedures and according to two different standards. An alternate possibility, the extension of the GVW range of the LDV category does not seem reasonable because of the demonstrated dependence of the MDV emissions on weight. Hence a complex revision of LDV standards would be implied.

Two possibilities are likely for an upper GVW limit; 10,000 lbs. and 14,000 lbs. Based solely on GVW ranges of vehicles, the 10,000 lb. limit is preferable since only one current year model overlaps this level. Limited-scope usage data provide no basis for discrimination. On the other hand, sales data for the 6,000-10,000 lb. GVW group and the similarity of vehicle characteristics and usage of this group with that of the LDV category favor the 10,000 lb. GVW limit. Also, the choice of the larger weight limit would bring very few additional trucks under control. Therefore, despite a lack of preponderant evidence favoring a specific weight limit, the 10,000 lb. GVW figure is recommended as the upper weight limit for the MDV category.

Motor home population is not as stratified by weight as it is for trucks. Sales and sales projections show a high popularity of the 10,000-14,000 lb. GVW group. Consequently, the limits for motor homes are recommended to range from 6,000 to 14,000 lbs. GVW.

e. Emission Control Approaches

Reduction of exhaust emissions from medium duty vehicles may be realized by (1) modifications of the conventional gasoline engine and/or exhaust gas after-treatment and (2) the use of alternate, low-emissions engines.

Emission control systems evaluated for MDV applications were chosen from those developed and, to a reasonable extent, tested in LDV applications. These systems offer a wide range of reduction potential and permit a cost-effective analysis to be made. The systems components include: engine modifications (EM^o), electronic ignition (EI), fast choke (FC), improved carburetion (IC), further improved carburetion (FIC), exhaust manifold air injection (AI), quick-heat intake (QHI), exhaust gas recirculation (EGR), oxidizing catalyst (OC), reducing catalyst (RC), air injection ahead of catalyst (CAI), controlled air injection (AI/CAI), electronic fuel injection and control (EFIC), three-way catalyst (RC/OC), lean thermal reactor (LTR), rich termal reactor (RTR) and improved quick heat manifold (IQHI). From this group of techniques/devices, a total of eight control systems was identified as shown in the accompanying tabulation. For each system the emission reductions for HC, CO and NO_x have been estimated (Table 2.14, page 2-68) together with the corresponding fuel penalties (Table 2.15, page 2-73).

Emission Control Systems for Conventional Gasoline Engines

Number	System[a]
0	EM^o [b]
1	EM^o + EI + FC + AI + EGR
2	EM^o + EI + IC + QHI + AI + EGR
3	EM^o + EI + IC + QHI + EGR + AI + OC
4	EM^o + EI + IC + QHI + EGR + RC + AI/CAI + OC
5	EM^o + EI + EFIC + EGR + RC/OC
6	EM^o + EI + IC + QHI + EGR + LTR
7	EM^o + EI + FC + EGR + AI + RTR
8	EM^o + EI + FIC + IQHI + AI + EGR

(a) Components are described in Appendix A-4.

(b) Modifications corresponding to 1972 model year engines.

Estimates of emission reduction were made primarily from the experience and data for these systems in light duty applications. There are substantial differences between the LDV and MDV classes that affect the control of emissions. First, the horsepower-to-weight ratio of the LDV class is relatively high and sensibly independent of vehicle weight. In the MDV class, this ratio tends to decrease with vehicle weight so that the engine operates at a higher power loading. Second, the MDV class uses higher numerical axle ratios resulting in higher engine speeds at a given vehicle velocity.

Of the alternative engines, only the lightweight diesel and the prechamber, stratified-charge (CVCC) engine are considered the most promising at present for the MDV class. The advanced lightweight diesel engine is visualized as being turbocharged and using a prechamber design. It is judged to be approximately 25% heavier and larger than comparable gasoline engines but with much lower baseline emissions and fuel consumption. This study presumed that the emission and fuel consumption characteristics of the contemplated lightweight diesel would be the same as those of current heavy duty diesels of this type.

Estimated baseline emission data for diesel-equipped MDV are shown in Figure 2.18 (page 2-97). Since diesel engine emissions data are available only from engine dynamometer tests, an improvised conversion of these data to driving cycle (gm/mile) results was necessary. Baseline emission levels for HC and CO for the lightweight diesel engine appear to be low enough. that no further control will be necessary. Reduction of NO_x levels by about one half is feasible with only a small fuel penalty with the addition of EGR.

The Compound Vortex Controlled Combustion (CVCC) engine recently developed by Honda is a modification of the basic, spark-ignition, gasoline engine. A variety of the stratified-charge engine, it demonstrates the low emissions of this type engine. A number of vehicles equipped with 4-cylinder and 8-cylinder CVCC engines have satisfied HC and CO standards for 1975 without any external control devices. Low levels of NO_x were also achieved without EGR. Because of very limited emissions data, and no durability data on CVCC engines of a horsepower range useful for MDV applications, further design and developmental testing of the V-8 engines is necessary. Continued promising results will make the CVCC engine an attractive alternative candidate for medium duty vehicles.

f. Emission Control Strategies

From the eight emission control systems (identified in a previous tabulation) and their associated lead times, three basic control strategies were selected for analysis of effectiveness to illustrate the range of choices possible using conventional gasoline engines. These three involve the use of: (1) improved means of fuel control (systems numbered 2 and 8), (2) catalytic converters (systems numbered 3, 4 and 5) and thermal reactors (systems numbered 6 and 7).

In implementing these strategies, lead time considerations dictate that, in some cases, a combination of two strategies is used. This is illustrated by the following combinations that were investigated.

Fuel Control Strategy

	Control System No.	Model Years Used
(A)	2	1975 onward
(B)	2	1975-1977
	8	1978 onward

Thermal Reactor Strategy

2	1975-1976
6	1977 onward

Catalytic Converter Strategy

2	1975-1976
3	1977-1978
5	1979 onward

Fuel control strategy (A) represents a minimum approach to emission reduction with a mean reduction of approximately 40% in each of the three principal pollutant from 1972 baseline levels. The catalytic converter strategy corresponds to the most stringent control schedule and accomplishes this at a relatively small fuel penalty. Because of its high fuel penalty, the rich thermal reactor (system no. 7) was not considered a viable approach and hence was disregarded in the analysis.

A computer program was developed to calculate total annual emissions and related costs for the medium duty vehicle category during the time period 1970-1990 for each of the above listed strategies. This program divided the MDV category into trucks and motor homes, each with two weight groupings (6, 000-10,000 lbs. and 10,000-14,000 lbs.). Vehicles of each model year were characterized by engine type and control system used. For each vehicle/engine/control system, emissions, fuel consumption and initial/operating costs were determined. Baseline emissions and fuel consumption data for each model year vehicle/engine combination were entered into the program together with factors which described the impact on each by the individual control strategies. The analysis did not include a consideration of control system durability. Data on annual vehicle mileage was also entered according to vehicle type (truck or motor home) as well as model year. Using sales data (projected and actual) and vehicle scrappage rage, the vehicle mix on the road in any year was calculated by the program.

Computer runs were made for two different MDV populations. One which consisted only of conventional gasoline engines and, the other, which used a mix of conventional and diesel engines. In all cases the conventional gasoline was a 350 CID V-8 and the diesel was taken to be an equivalent engine (turbocharged, prechamber, with EGR and with the same displacement).

With the homogeneous population of conventional engines, the strategy based on catalytic converters represented the greatest reduction of all pollutants by a significant margin during the 1980's (Figures 2.19-2.21, pages 2-118 to 2-120). The corresponding fuel penalty, however was only slightly higher than that of the most economical strategy, the fuel control strategy (B) (Figure 2.25, page 2-125). If diesels are introduced to produce a heterogeneous engine mix, the catalytic converter strategy still provides the greatest emissions reductions but now the fuel control strategy (B) is only slightly less effective (Figures 2.22-2.24, pages 2-121 to 2-123). Some loss of NO_x control, relative to the case of using conventional engines only, is experienced. On the other hand, a sizable savings in fuel consumption occurs with diesel engines replacing gasoline engines (Figure 2.26, page 2-127).

3.0 PART B. ECONOMIC ANALYSIS

1. Summary and Conclusions

The purpose of this study was to develop and analyze the relationships between different emission control levels and the cost-of-ownership of representative 6,000 - 14,000 lbs. GVW vehicle/engine types equipped with various engine-emission control systems. The costs considered are the incremental costs incurred from the employment of the emission control systems. The base line is the 1972 spark ignition engine.

The study encompassed eight emission control systems for use with existing spark ignition engines and the introduction of a new family of diesel engines. The former can be classified into three broad categories: improved carburetion (fuel control), thermal reactors and catalytic converters. The categories, however, are not mutually exclusive. For example, improved carburetion features are also used with thermal reactors and catalytic converters. The diesel engines considered in the study are new or modified designs of present engines with matched torque converters and automatic transmissions.

Estimated lead times for the spark ignition engine emission control systems range from 2-5 years. Lead times of 8-10 years would be needed to reach full production for a new family of diesel engines. This lead time could be reduced to about 5 years if the objective was to develop one diesel engine which could have widespread applicability in medium duty vehicles.

The use of improved carburetion for emission control of spark ignition engines together with the introduction of diesel engines appears as the best control strategy for medium duty vehicles. This approach would reduce annual emissions of HC, CO and NO_x by 77, 81 and 64 per cent, respectively by 1989. This reduction is relative to 1972 base line engines. The 15 year cost of this approach is $2 billion.

A small further improvement particularly in NO_x emission reductions can be achieved by a mix of diesel and standard gasoline engines where the latter are equipped with catalytic converter systems. The 15 year cost of this approach is considerably higher, $3.4 billion.

Diesel engines equipped with EGR result in significant emission reductions and at the same time provide good fuel economy. Fuel savings more than offset the higher initial price of such engines.

The improved carburetion and catalytic converter approaches are the systems of choice in the absence of diesel engines. Implementation of the former systems will result in the reduction of all pollutants by about 60 per cent by 1989 at a total cost of $3.7 billion. The latter systems will reduce emission levels of HC by 79, CO by 72 and NO_x by 83 per cent by 1989. The cost incurred, however, is $5.3 billion.

Lean thermal reactor and improved carburetion result in about equal effectiveness. The former costs more, primarily because of the higher fuel penalty associated with it.

A detailed comparison of the effectiveness, costs and lead times of the considered systems is contained in Section 3.7 commencing on page 3-50.

The cost per mile of vehicle operation attributable to pollution control systems is generally less than $.01 per mile. The potential impact of this cost on lease charges is, therefore, not considered significant.

Precise estimates of certification costs cannot be made until the requirements, engine families and vehicle types are firmly defined. A crude, preliminary analysis indicates, however, that the potential impact of certification costs could represent a significant cost, particularly for the smaller manufacturers.

2. Supporting Discussion

a. Emission Control Systems and System Effectiveness

The emission control systems and their estimated effectiveness considered in the economic analysis represent inputs from the Part A Technical Analysis.

b. Sales Projections

Sales projections formed the basis for estimating the total costs and reductions in emissions which could be achieved by implementing the emission control systems.

The vehicles within the 6,000-14,000 lbs. GVW range fall into two clearly demarcated weight categories; 6,000-10,000 lbs. and 10,000-14,000 lbs. In recent years, the former have accounted for 20-24 per cent of all U.S. sales of trucks and buses, the latter for less than 2 percent.

Sales projections for vehicles in the 6,000-10,000 lbs. GVW class were made both in total and as a function of body type: pickup, van/panel, multistop van and chassis. In 1971, sales of this class of vehicles consisted of about 500,000 units. This number is estimated to increase to 650,000 units by 1976 and slightly more than 800,000 units by 1980. Pickup trucks represent between 50 and 60 per cent of the vehicles in this class.

Between 1958 and 1970, annual sales of 10,000-14,000 lbs. GVW vehicles fluctuated between 5,000 and 15,000 units. Sales rose sharply, thereafter, principally attributable to the popularity of motor homes. The rate of increase in annual sales between 1970 and 1972 (from 7,000 to 45,000) is not estimated to be sustained. Rather, a more moderate increase is postulated resulting in annual sales of about 80,000-100,000 units by 1980.

Vehicles in the 10-14,000 lbs. GVW category consist primarily of multistop and chassis body types. No pickups or van/panel trucks of this weight are manufactured.

Sales projections for 6,000-14,000 lbs. GVW vehicles are presented in Section 3.3 of the report.

All the body types noted in the previous paragraphs can be and are used as recreational vehicles. The latter can be divided into two categories: truck campers and motor homes. According to "Recreational Vehicles Facts and Trends", the annual sales of truck campers rose from 61,000 units in 1967 to 107,200 in 1971. Comparable sales for motor homes are 9,050 and 57,200.

c. Costs

The cost measure used for system comparison is the sum of the initial sticker price of the emission control systems, incremental maintenance and fuel costs for the specified number of miles. Costs are estimated for three representative engine families: I6-300 CID, V8-350 CID and V8-454 CID. Anticipated low and high cost estimates were developed for all systems.

The sticker prices of emission control systems for spark ignition engines range from about $100 to $300. The first system incorporates improved carburetion and electronic ignition; the second oxidizing and reducing converters. The estimated incremental sticker prices of diesel engines is $400-$800 depending on engine size.

Incremental maintenance costs associated with spark ignition engines range from about $10 to $300-$400 (based on 50,000 miles of travel). The relatively low costs of some systems result from cost savings obtained through the use of electronic ignition. The high cost systems are those which require periodic replacement of oxidizing and/or reducing catalytic converters.

The emission control systems of spark ignition engines cause fuel penalties ranging from 3 to 25 per cent compared to 1972 baseline engines. In contrast, diesel engines result in significant fuel savings because of their lower fuel consumption. Anticipated incremental fuel costs for spark ignition engines range from $90 to $1,000 based on 50,000 miles of operation and a fuel cost of $0.45 per gallon. Fuel cost savings with diesel engines vary between $650 and $1,400 depending on engine size.

Total incremental costs (i.e., sticker price + incremental maintenance + incremental fuel) for spark ignition engines vary between $350 and $1,500 based on 50,000 miles of travel. In comparison, diesel engines show cost savings of $300-$700. The higher initial sticker prices of diesels is more than offset by their fuel economy.

Emission control system costs are developed in Section 3.5 of the report.

d. Lead Times

The estimated lead times are predicated on a sequential progression of activities culminating in initial production. The emission control systems considered are presently in various stages of development. Their current status is considered in determining the lead times.

Improved carburetion together with electronic ignition could be achieved in 2 years. Systems employing catalytic converters and thermal reactors require lead times of 4 to 5 years. A major lead time category here is the construction of new plant facilities and associated tooling. As noted earlier, achievement of production of a family of diesel engines would require 8-10 years. The production of one engine with wide applicabilility, such as a 350 CID diesel engine, given the necessary priority, could be achieved in about 5 years. Lead time requirements are presented in Section 3.6 of the report.

1.0 INTRODUCTION

In the furtherance of improved air quality, it is prudent to require that motor vehicles utilize available control technology to achieve a reduction of pollutant emissions to the lowest cost effective levels. This desirable condition can be achieved by the promulgation of the appropriate emission standards for new vehicles by the Environmental Protection Agency.

The present study, concerned with a technical evaluation of emission control approaches and the economics of emission reduction, has focussed on that category of vehicles with a gross vehicle weight (GVW) in the range from 6,000 to 14,000 lbs. In the interests of a concise notation, this category of vehicle is arbitrarily referred to as a medium duty vehicle (MDV) in this report to differentiate it from the well-established light duty (LDV) and heavy duty vehicle (HDV) designations.

In assessing the advanced control technology that may be adapted to the medium duty vehicle to reduce emissions, it is necessary to identify specific control approaches, determine their developmental status and estimate their expected effectiveness in the intended application and service. With the different control approaches attaining production status at different dates, a variety of control strategies can be postulated as a function of emission reduction capability, time and attendant costs which include system initial costs and those related to added maintenance and operational expenses. From this data base, the objectives of achieving a reduction of emissions from the MDV by an amount that is within the capability of the state-of-the-art technology and is also cost effective can be achieved. This report describes the studies conducted in interests of meeting these objectives.

Program effort was conducted along two separate technical disciplines: technical analysis and economic analysis. The objective of the technical analysis was to conduct a technical evaluation of emission control approaches and emission reduction levels applicable to medium duty vehicles in the range from 6,000 to 14,000 pounds GVW. This objective was to be achieved by adopting a methodology that involved: an identification and characterization of the vehicles comprising this weight group, the selection of current model year vehicle/engine combinations best representative of this population together with the establishment of their baseline emission data, the selection of emission control techniques and advanced engine concepts for purposes of achieving emission reductions and the estimation of the reductions thereby feasible, the identification of the levels of emission control possible as a function of lead time and vehicle performance penalties and, finally, a discussion of the optimum levels of emission reduction possible considering performance penalties and lead times. This study relied on the presumption that further emission reductions could be achieved in the medium duty category of vehicles by adapting to them the extensive emission control technology/devices/components that have been developed for light duty vehicles. A purely analytical evaluation of the efficacy of the LDV control technology in these vehicles is feasible because of the commonality of engines/drivetrains in both the LDV and MDV vehicles.

Results of the technical analysis portion of the program are presented in Part A of this report.

The economic analysis, Part B of the study, was designed to develop and analyze the relationships between different emission control levels and their associated implementation costs for representative vehicle-engine types which comprise the medium duty class of vehicles.

Initially, the sticker prices and maintenance costs of the devices which comprise the postulated emission control systems are estimated. These are then combined into system costs. The latter also include the cost of incremental fuel penalties or savings which are incurred with the systems. The resultant costs are then compared with system effectiveness for various emission control strategies. The comparison is made both in terms of individual vehicle emissions and for aggregations of the total population of medium duty vehicles.

The results of the study are presented in Part B of this study which commences with Section 3.0.

2.0 PART A: TECHNICAL ANALYSIS

2.1 Summary, Conclusions and Recommendations

A survey of the literature related to motor vehicles that populate the 6,000 to 14,000 pound GVW range shows that their engine and drivetrain components are usually identical to, or direct derivatives of, light duty vehicles. The pickup truck dominates this group in number and, being a dual-purpose vehicle, gives this class of vehicles a usage and operating character similar to the light duty vehicle. A singular exception is the motor home whose current popularity gives it an appreciable share of the annual sales in this GVW range.

Adapting emission control technology as developed for the light duty vehicle, a number of emission control systems are postulated as appropriate for medium duty vehicles. Emission reduction factors, fuel penalties and effects on vehicle performance are estimated on the basis of experimental results obtained with light duty vehicles. Three general categories of emission control approaches are identified: the catalytic converter, the thermal reactor and the improved fuel control (carburetion/induction).

Baseline emission data are developed for the medium duty vehicle group using test data provided from a sample of late model medium duty vehicles subjected to an equivalent 1975 Federal Test Procedure. These data show that the dominant factor affecting emissions is the vehicle weight.

Emission control strategies are devised by combining emission control systems and alternative engines with the projected lead time data associated with each. A computer simulation procedure is used to predict the consequences in terms of emission reductions achieved and fuel penalties incurred with the implementation of each of these control strategies. Durability of emission control systems is not included as a part of this analysis.

The results of the technical analysis study support the following conclusions and recommendations (subject to the limitations noted in the text of this report).

- Exhaust emissions from late model vehicles in the 6,000-14,000 lb. GVW category are primarily a function of weight.

- The most effective control strategy for HC and CO emissions visualizes the medium duty vehicle category using a mix of conventional engines equipped with catalysts and diesel engines (prechamber, turbocharged, with EGR).

- The best fuel economy is achieved with the control strategy cited above.

- The most effective control strategy for NO_x emissions visualizes the medium duty vehicle category using conventional engines equipped with catalysts.

- In setting emission standards for medium duty trucks, it is recommended that the GVW limits be set at a minimum of 6,000 lbs. and a maximum of 10,000 lbs.

2.2 Methodology

The technical approach or methodology followed in the conduct of this project was generally consistent with the explicit procedural outline specified by EPA in the contractural statement of work. A succinct summary of this outline is provided in the block diagram of Figure 2.1 where the individual blocks are serially numbered to indicate a chronological sequence of execution. In practice, it was found necessary to iterate to some extent as new or additional information required revision of tentative judgments or conclusions arrived at in an earlier stage of the project.

The initial task involved the identification of the types of vehicles comprising the 6,000 - 14,000 pound GVW category in terms of population, sales, usage, ranges of GVW, engines, drivetrains and other unique characteristics. With these data accumulated, vehicle groups were formulated for the purpose of validating/recommending the GVW limits for the new category of medium duty vehicles. For each group thus identified, a representive vehicle/engine/drivetrain combination was selected to best reflect all ordinary combinations within that group. For each representative combination, the current model year emission controls were enumerated and the associated baseline emission levels determined. These emission data, which were measured using a test procedure equivalent to the 1975 Federal Test Procedure (FTP) for light duty vehicles, were supplied by EPA.

Drawing upon the state-of-the-art of emission control technology as developed for light duty vehicles, a number of likely control system combinations was selected as potentially applicable to medium duty vehicles. For each such combination identified, estimates were to be made concerning emission reduction factors, effects on vehicle performance and lead times required for implementation.

Emissions data available for medium duty trucks did not permit discrimination among the group of vehicle/engine/drivetrain combinations

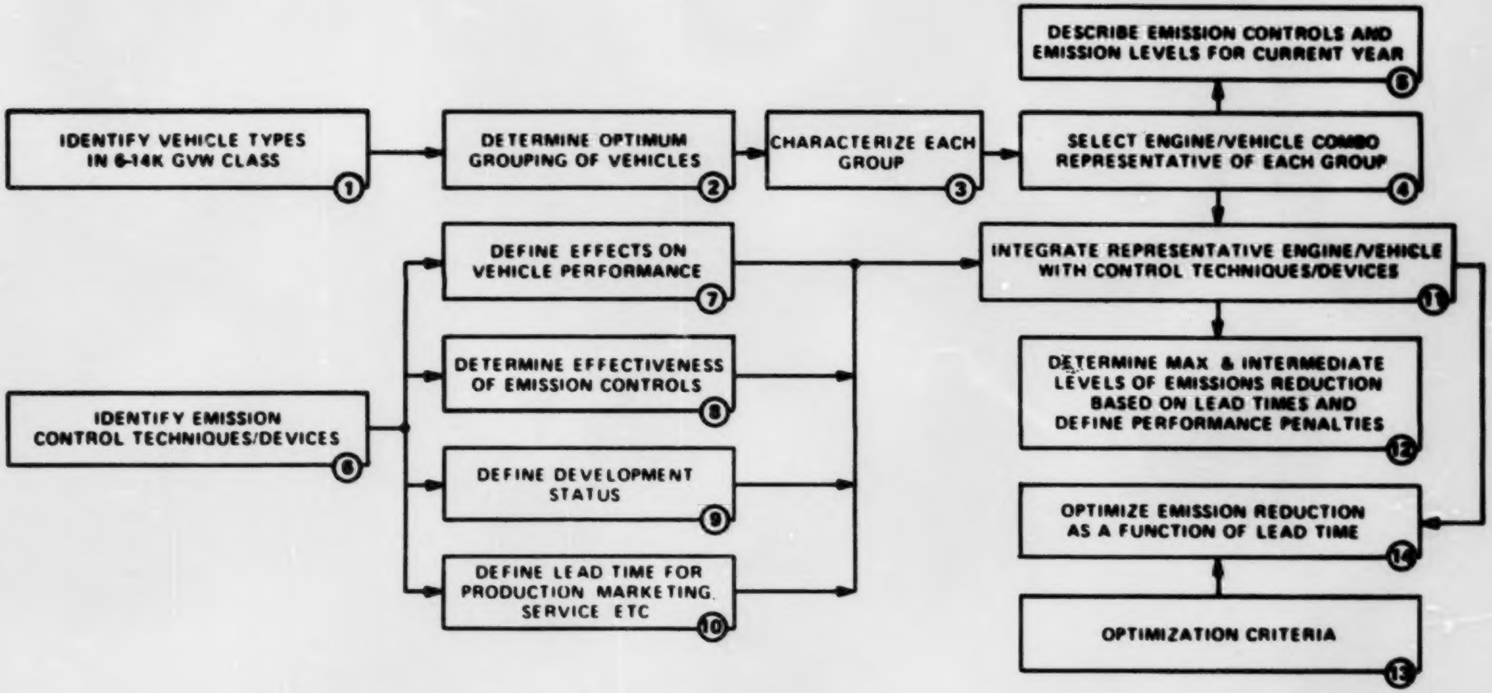
IDENTIFY VEHICLE TYPES IN 6-14K GVW CLASS
1
DETERMINE OPTIMUM GROUPING OF VEHICLES
2
CHARACTERIZE EACH GROUP
3
SELECT ENGINE/VEHICLE COMBO REPRESENTATIVE OF EACH GROUP
4
DESCRIBE EMISSION CONTROLS AND EMISSION LEVELS FOR CURRENT YEAR
5
IDENTIFY EMISSION CONTROL TECHNIQUES/DEVICES
6
DEFINE EFFECTS ON VEHICLE PERFORMANCE
7
DETERMINE EFFECTIVENESS OF EMISSION CONTROLS
8
DEFINE DEVELOPMENT STATUS
9
DEFINE LEAD TIME FOR PRODUCTION MARKETING, SERVICE ETC
10
INTEGRATE REPRESENTATIVE ENGINE/VEHICLE WITH CONTROL TECHNIQUES/DEVICES
11
DETERMINE MAX & INTERMEDIATE LEVELS OF EMISSIONS REDUCTION BASED ON LEAD TIMES AND DEFINE PERFORMANCE PENALTIES
12
OPTIMIZE EMISSION REDUCTION AS A FUNCTION OF LEAD TIME
14
OPTIMIZATION CRITERIA
13

Figure 2.1 PROGRAM INFORMATION FLOW CHART

selected. The principal discriminant factor was found to be vehicle inertia (test) weight so that the operation indicated in block number 11 (Figure 2.1) was not required. Using lead time data as the determining factor, various implementation strategies were defined corresponding to the most stringent schedule of emission reduction as well as lesser intermediate levels. Based on differing objectives, "best" control approaches to emissions reduction were considered. In performing this task a computer program was employed to calculate the estimated annual emissions and costs in applying the various control strategies to the medium duty class of vehicles.

The succeeding sections of this report discuss in detail the findings, the results and the conclusions of the studies conducted in the application of the above methodology in the furtherance of the objectives of the program.

2.3 VEHICLE CHARACTERIZATION

2.3.1 Types and Grouping

A study of the manufacturer's truck sales handbooks and the statistical summaries* published by the Motor Vehicle Manufacturers Association (MVMA) shows that the entire population of motor vehicles comprising the 6,000 - 14,000 GVW category may be classified as trucks designed to transport cargo and persons for personal, business and recreational purposes. The listing given below characterizes this category of vehicles according to body style.

Truck Vehicle Types (6,000-14,000 lbs. GVW)

- Pickup
- Passenger Van
- Panel
- Van
- Multi-Stop Van
- Cab chassis
- Cowl chassis
- Bare chassis
- Motor Home chassis
- Camper Special

In terms of basic vehicle structures there exist only seven varieties rather than the ten tabulated above. The pickup and the camper special are identical except the latter designation indicates the use of a heavy duty suspension to accommodate a camper unit. This unit is either built permanently upon the vehicle or else a "slide-in" demountable camper body is used. For recreational purposes, the pickup may also be equipped with a portable cover to provide an all-weather protective enclosure over the bed of the truck. Similarly the van and passenger van share a common body structure except that in the latter, passenger seats replace the nominal cargo space and windows are added in the body side panels. Only one model of the entire passenger van line qualifies for classification as a heavy duty vehicle (see Section 1.0 for qualifications). This sole exception is the 15-passenger van (Model B-300) made by the Dodge Division of Chrysler Corporation. The panel truck is not a popular body style and sales in recent years have decreased to an insignificant level*. Motor homes are classified into three distinct categories: conventional, van version, and chopped-van. The conventional type is built upon a bare heavy-duty truck chassis. The van version converts the nominal interior cargo space of a van into living quarters whereas the chopped-van type is built directly on the aft frame section of a van truck retaining the forward section as the driver compartment. Figure 2.2 illustrates the basic body styles of the 6,000 - 14,000 lb. GVW group of vehicles.

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*Annual issues of "Motor Truck Facts"

As indicated in Section 2.2 (Methodology), the initial intent was to group the vehicles on the basis of information on usage, sales and vehicle physical characteristics (weight, engine, drivetrain, etc.). Usage, interpreted to include such factors as weight of load, trips per day, daily mileage, etc. was considered especially significant in its effect on emissions. While an attempt was made to pursue this approach early in the program, a lack of definitive usage data for this category of vehicles (see Section 2.3.4 for a discussion of available usage information) necessitated adoption of a different strategy. Instead, vehicle groups were formed on the basis of judgment and pragmatic considerations using the limited information available. The validity of the selections was then tested by checking for inconsistencies as additional data were obtained or developed. There was no subsequent need to change this grouping which is tabulated on the following page.

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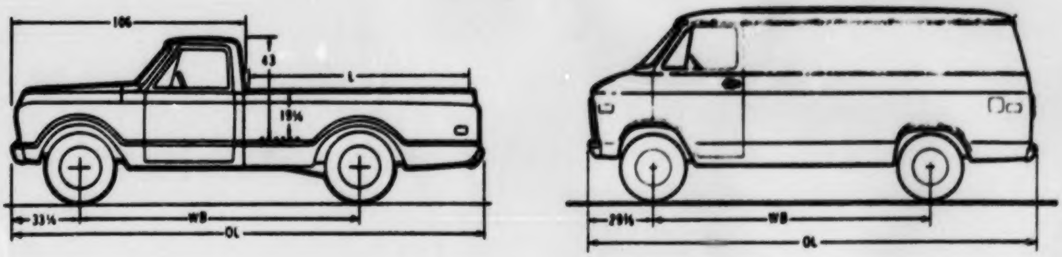
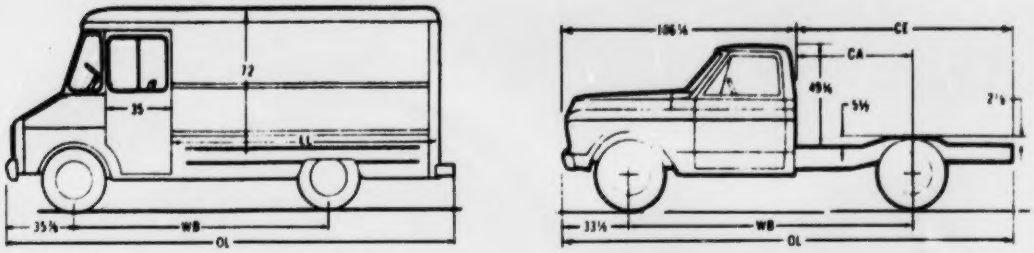
*Domestic factory sales: 1970 - 777, 1971 - 181; Source: MVMA



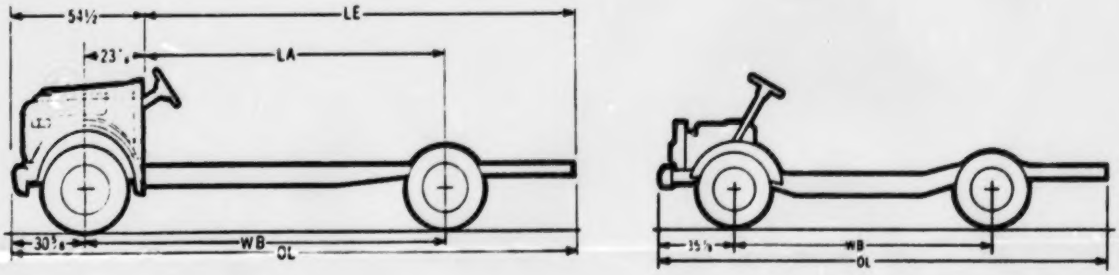
PICKUP

VAN



MULTI-STOP VAN

CAB CHASSIS



COWL CHASSIS

BARE CHASSIS

NOTE: ONLY TYPES PRESENTLY CLASSIFIED AS HEAVY DUTY ARE CONSIDERED (REF. GMC 1972 TRUCK MANUAL).

Figure 2.2 MAJOR TYPES OF BODY STYLES (6,000 - 14,000 LB GVW)

TABLE 2.1

Vehicle Grouping

Group	Body Style Included
Pickup/Camper	Pickup Camper Special
Van/Passenger Van	Van Passenger Van
Multi-Stop Van	Multi-Step Van
Chassis	Cab Chassis Cowl Chassis Bare Chassis
Motor Home Chassis	Motor Home Chassis

A brief, qualitative explanation for the rationale underlying these selections is presented below. Specific, quantified information is contained in the three succeeding sections (2.3.2 - 2.3.4).

Pickup/Camper Group: Sales data show the pickup is an extremely popular vehicle which has dominated sales of trucks with a GVW of 10,000 lbs. and less. Its primary use appears to be about equally divided between personal and business functions and it tends to be operated in a manner similar to that of the passenger automobile. With the addition of a camper unit, the pickup also assumes the role of a recreational vehicle. This feature, however, does not create a single-purpose vehicle and hence the camper version is included in the pickup group.

Van/Passenger Van(/Panel) Group: This group essentially consists of only the forward control van which is principally used in the wholesale and retail trade with a GVW range that does not exceed 10,000 lbs. The panel truck is included primarily because it needs to be accounted for in the presentation of sales of medium duty trucks in previous years (Section 2.3.3). U. S. domestic sales data for the 12-month period ending December 31, 1972, (MVMA FS-20) show that no panel trucks with a GVW over 6,000 lbs. were produced. The passenger van category, as cited earlier, includes only one model of one manufacturer.

Multi-Stop Van: Multi-stop, or step vans, comprise a unique vehicle group characterized by ownership and usage that is entirely commercial. The principal usage patterns are also unique reflecting a stop-idle-go type of delivery and pick-up service on fixed routes (home milk delivery, for example) or variable routes (parcel delivery). This group of vehicles appears to be concentrated in urban areas and especially the central business districts of large metropolitan areas (New York City is one identifiable example, Reference 2).

Chassis: Vehicles in the chassis group are manufactured and sold without bodies. Specialized body builders complete the manufacture of the vehicle by constructing the body portion in accord with the intended functional usage. Cab chassis types are generally fitted with a box-style body while the cowl chassis is usually bodied as a bus. Bare chassis units are often of the forward-control variety and are converted into multi-stop van configurations. This group, at its upper GVW end, includes vehicle types whose GVW limits range well above 16,000 lbs. Because of the many special use vehicles that originate from these general chassis types, a concise statement concerning usage is not feasible. Broadly stated, the uses are commercial, industrial and agricultural.

Motor Home Chassis: The motor home chassis is purchased by specialized manufacturers who complete the construction of the motor home. As a result of the popularity of this type vehicle, some of the major manufacturers (Ford and GM, for example), contrary to prior practice, are now producing the entire vehicle themselves. The separate classification of this group is unequivocal. As a group, they are unique, single-purpose vehicles probably operated near rated GVW. Their principal usage is for vacation/week-end trips. Vacation trips may consist of one or two extended trips (1,000 - 2,000 miles) while week-end trips, averaging several hundred miles each, may be highly variable in number. The motor home is operated infrequently in urban areas and probably is unused for much of the year.

2.3.2 Engines, Drivetrains and GVW Ranges

An important part of vehicle characterization is the identification of the engines, transmissions and axle ratios that are employed in the 6,000 - 14,000 GVW range of trucks. In general, all of these parameters tend to be loosely correlated with vehicle gross weight, that is, the engine displacement and numerical axle ratio will usually increase with weight. All of these factors would also be expected to impact on the emissions of the vehicle.

Using the manufacturer's truck sales handbooks for 1973, the following data were gathered for each of the major manufacturers vehicle models in the 6,000 - 14,000 lb. GVW range: model designation, body type, axles, GVW, GCW (curb weight), engine (number of cylinders and CID), type transmission and numerical axle ratio. A summary of this information is given in Table 2.2 where the vehicles are arranged by the groups identified in the previous section.

A number of significant and interesting observations can be made from this compilation. One relates to the GVW specifications. All of the vehicles included within the pick up/camper and van/passenger van groups have GVW ranges totally contained within the range from 6,000 to 10,000 lbs. Also, in the case of the remaining three groups (multi-stop vans, chassis and motor home chassis) all of the models, with but a single exception, have GVW ranges either between 6,000 - 10,000 lbs. or above 10,000 lbs. The lone exception is the Chevy/GMC P30/P35 model with a 7,600 to 14,000 lb. GVW range.* On the other hand, a number of models are shown with ranges that exceed, or overlap, the 14,000 lb. level from below. Considering the 6,000 lb. level from below, one finds that there are a number of vehicles with a maximum GVW of 6,000 lbs. but, again,

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* MVMA sales data for the past two years fail to show any sales of GM vehicles with a GVW rating in the 10,000-14,000 lb. range despite the availability of this model.

TABLE 2.2

VEHICLE-ENGINE-DRIVETRAIN CHARACTERIZATION - 1973 MODELS

GROUP 1: PICK UP/CAMPER

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Dodge D-200	Pickup and Camper Special	4x2	6.2- 9.0	3245-4011	6-225	110	M3	4.10
					8-318	150	A3	4.10
					8-360	180	A3	4.10
					8-400	200	A3	4.10
Dodge D-300	Pickup	4x2	6.6-10.0	3795-5240	6-225	110	M3	4.56
					8-318	150	M3	4.56
					8-360	180	M3	4.10
					8-400	200	A3	4.10
Dodge W-200	Pickup	4x4	6.5-8.0	3810-4555	6-225	110	M3	4.10
					8-318	150	M3	4.10
					8-360	180	A3	4.10
					8-400	200	A3	4.10
Dodge W-300	Pickup	4x4	8.5-10.0	4320-5335	6-225	110	M3	4.88
					8-318	150	M3	4.88
					8-360	180	M3	4.88
					8-400	200	A3	4.88
Ford F-250	Pickup	4x2	6.2-8.1	3520-3940	6-300	114	(M3)	(4.10)
					8-360	148	(M3)	(3.73)
					8-390	161/153	(A3)	(3.73)
Ford F-250	Pickup	4x4	6.5-7.7	3965-4385	6-300	114	M4	4.10
					8-360	148	(A3)	4.10
Chevy/GMC C20/C25	Pickup	4x2	6.4-8.2	4014-4916	6-250	100	(M3)	(4.10)
					6-292	120	(M3)	(4.10)
					8-307	130	(M3)	(4.10)
					8-350	155	(A3)	(4.10)
					8-454	240	(A3)	(3.21)

GROUP 1. (continued)

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Chevy/GMC C30/C35	Pickup	4x2	6.6-10.0	4213-4921	6-250	100	(M3)	(4.10)
					6-292	120	(M3)	(4.10)
				4340-5048	8-307	130	(M3)	(4.10)
					8-350	155	(M3)	(3.73)
					8-454	240	(A3)	(3.73)
Chevy/GMC K20/K25	Pickup	4x4	6.8-8.2	4313-4438	6-250	100	(M3)	(4.56)
					6-292	120	(M3)	4.56
				4448-4573	8-307	130	(M3)	4.56
					8-350	155	(A3)	(4.10)
I-H- 1210	Pickup	4x2	6.3-8.2	3510-4050	6-258	113	(M4)	4.10
					8-304	137	(M3)	4.10
					8-345	144	(M3)	3.73
					8-392	179	(A3)	3.73
		4x4	6.3-7.7	3820-4305	6.258	113	(M4)	4.10
					8-304	137	(M3)	4.10
					8-345	144	(M3)	4.10
					8-392	179	(M3)	4.10
I-H 1310	Pickup	4x2	7.0-10-0	3715-4155	6-258	113	(M5)	4.87
					8-304	137	(M4)	4.87
					8-345	144	(M4)	4.30
					8-392	179	(A3)	4.30
		4x4	7.0-10.0		6-258	113	(M4)	4.87
				4375	8-304	137	(M4)	4.87
					8-345	144	(M4)	4.87
					8-392	179	(M4)	4.87
Ford E-300	Camper Special	4x2	8.3	3655	8-302	139	A3	3.73

GROUP 2: VAN/PASSENGER VAN

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Dodge B-300	Pass. Van		6.2-7.7	4035-4210				
	Van	4x2	6.2-8.2	3695-3985	6-225	110	A3	4.10
					8-318	150	A3	4.10
					8-360	180	A3	4.10
Ford E-300	Van	4x2	6.0-8.3	3845-4015	6-300	118	(M3)	(4.10)
					8-302	139	(A3)	(3.73)
Chevy/GMC G30/G35	Van	4x2	6.2-7.9	3886-4046	6-250	100	(M3)	4.56
			6.2-8.3	4052-4212	8-350	155	(A3)	(4.10)

GROUP 3: MULTI-STOP VAN

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Chevy/GMC P20/P25	Multi-Stop Van	4x2	6.8-8.0	4701-5578	6-250	100	(M3)	(4.56)
					6-292	120	(M3)	(4.56)
				4849-5676	8-307	130	(M3)	(4.56)
					8-350	155	(A3)	(4.56)
Chevy/GMC P30/P35	Multi-Stop Van	4x2	7.6-14.0	4870-6010	6-250	100	M4	(4.56)
					6-292	120	A3	(4.10)
				5018-6158	8-307	130	M4	(4.10)
					8-350	155	(A3)	(4.10)
					8-454	250	(A3)	(4.10)
I-H	Multi-Stop Chassis	.2	10.0-14.0		6-258	113	(M4)	4.56
					8-345	144	(M3)	4.87

GROUP 4: CHASSIS

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axles
Dodge D-200	Cab Chassis and Platform	4x2	6.2-9.0	3245-4040	6-225	110	M3	4.10
					8-318	150	A3	4.10
					8-360	180	A3	4.10
					8-400	200	A3	4.10
Dodge D-300	Cab Chassis	4x2	6.6-10.0	3795-5240	6-225	110	M3	4.56
					8-318	150	M3	4.56
					8-360	180	M3	4.10
					8-400	200	A3	4.10
Dodge W-200	Platform	4x4	8.5-10.0		6-225	110	M3	4.10
					8-318	150	M3	4.10
					8-360	180	A3	4.10
					8-400	200	A3	4.10
Dodge W-300	Cab Chassis and Platform	4x4	8.5-10.0	4320-5335	6-225	110	M3	4.88
					8-318	150	M3	4.88
					8-360	180	M3	4.88
					8-400	200	A3	4.88
Dodge MB300	Cab Chassis	4x2	8.2-9.0	3714-3826	8-360	180	A3	4.10
Dodge CB300 (P400)	Bare Chassis	4x2	13.6 -17.4	4025-4080	6-225	110	A3	4.10
					8-318	150	A3	4.10
					8-360	180	A3	4.10
Ford F-250	Cab Chassis	4x2	6.2-8.1	3520-3940	6-300	114	(M3)	(4.10)
					8-360	148	(M3)	(3.73)
					8-390	161/153	M4/A3	(3.73)
		4x4	6.5-7.7	3965-4385	6-300	114	M4	4.10
					8-360	148	(M4)	4.10

GROUP 4: (Continued)

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Ford F350	Cab Chassis	4x2	6.6-10.0	3740-5010	6-300	114	(M4)	(4.56)
					8-360	148	(M4)	(4.10)
					8-390	161/153	M4/A3	(3.73
Ford P350	Bare Chassis	4x2	6.1-8.0	2615-2770	6-300	114	(M3)	(4.56)
Ford P400	Bare Chassis	4x2	7.0-10.0	3100	6-300	114	(M3)	(4.56)
Ford P500	Bare Chasis	4x2	10.0-15.0	3805-3905	6-300	126	(M3)	(6.2)
Ford F500	Cab Chassis	4x2	14.0-19.2	4960-5090	6-300	114	(M4)	(6.2)
					8-330	137	(M4)	(5.83)
Chevy/GMC C20/C25	Cab Chassis	4x2	6.4-8.2	3619-4392	6-250	100	(M3)	(4.10)
				3754-4527	6-292	120	(M3)	(4.10)
					8-307	130	(M3)	(4.10)
					8-350	155	(A3)	(3.73)
					8-454	240	(A3)	(3.73)
Chevy/GMC C30/C35	Cab Chassis	4x2	6.6-10.0	3778-4401	6-250	100	(M3)	(4.10)
				3905-4528	6-292	120	(M3)	(4.10)
					8-307	130	(M3)	(4.10)
					8-350	155	(M3)	(3.73)
					8-454	240	(A3)	(3.73)
Chevy/GMC K20/K25	Cab Chassis	4x4	6.8-8.2	3918	6-250	100	(M3)	4.56
				4043	6-292	120	(M3)	4.56
					8-307	130	(M3)	4.56
					8-350	155	(A3)	(4.10)

GROUP 4: (Continued)

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
I-H 1210	Cab Chassis	4x2	6.3-8.2	3510-4050	6-258	113	(M4)	4.10
					8-304	137	(M3)	4.10
					8-345	144	(M3)	3.73
					8-392	179	(A3)	3.73
		4x4	6.3-7.7	3820-4305	6-258	113	(M5)	4.87
					8-304	137	(M4)	4.87
					8-345	144	(M4)	4.30
					8-392	179	(A3)	4.30
I-H-1310	Cab Chassis	4x2	7.0-10.0	3715-4155	6-258	113	(M5)	4.87
					8-304	137	(M4)	4.87
					8-345	144	(M4)	4.30
					8-392	179	(A3)	4.30
I-H-1310	Cab Chassis	4x4	7.0-10.0	4375	6-258	113	(M4)	4.87
					8-304	137	(M4)	4.87
					8-345	144	(M4)	4.87
					8-392	179	(M4)	4.87
I-H-1510	Cab Chassis	4x2	13.8-15.0	4620-4685	6-258	113	(M5)	5.57
					8-304	137	(M4)	5.57
					8-345	144	(M4)	4.87
					8-392	179	(M4)	4.87

GROUP 5: MOTOR HOME CHASSIS

Dodge M300/ R300	Motor Home Chassis	4x2	11.0	3575-3820	8-318	160	A3	4.88
					8-440	240	A3	4.56

GROUP 5: (Continued)

Vehicle	Type	Axles	GVW	GCW	Engine	HP	Trans.	Axle
Dodge M400/ R400	Motor Home Chassis	4x2	13.0		8-318	160	A3	4.88
					8-440	240	A3	4.56
Dodge R500	Motor Home Chassis	4x2			8-440	240	A3	4.56
Ford M400	Motor Home Chassis	4x2	8.0-10.0	3450-3550	8-360	148	A3	(4.10)
					8-390	153	A3	(4.10)
Ford M450	Motor Home Chassis	4x2	11.0	4135-4225	8-360	148	A3	(4.33)
					8-390	153	A3	(4.33)
Ford M500	Motor home Chassis	4x2	12.0-15.0	4135-4225	8-390	153	A3	(5.29)
Chevy/GMC P30/P35	Motor Home Chassis	4x2	7.6-11.8	3229-3348	8-350	155	A3	(4.10)
					8-454	250	A3	(4.10)
I-H	Motor Home Chassis	4x2	10.0-14.0		8-392	179	A3	4.87

Note: 1. Data included in ( ) are estimated

2. The Dodge 440 CID engine replaced the 413 CID on 1/1/73.

3. GVW is in thousands of pounds. GCW is in pounds.

only one model that exceeds it (the Chevy/GMC K10/K15 with a 4,900 to 6,200 lb. GVW range). Thus the 6,000 and 10,000 lb. levels represent clear dividing lines between vehicles according to gross vehicle weight.

The second point also relates to weight; the gross curb weight (GCW) of the vehicle. Vehicle curb weights are seen to be below 5,000 lbs. for the majority of the vehicles shown in Table 2.2. Thus, if EPA ultimately follows the current LDV certification practice of adding an incremental payload to the vehicle curb weight to specify an inertia (test) weight, a large fraction of the vehicles would be tested within a 6,000-lb. limit assuming weight increments of 500 to 1,500 lbs. Test weights for medium duty vehicles would thereby overlap the test weight range of light duty vehicles to a large extent.

Automobile manufacturers generally use the same basic engine families in both light duty vehicles and medium duty trucks as identified in Table 2.2. Engine families are defined as comprising engines which share a common engine block casting and an identical cylinder arrangement, bore spacing and deck height. Within an engine family, engines may have different displacements resulting from different bore and/or stroke dimensions. Horsepower ratings of engines with identical displacement may vary due to changes in carburetion, compression ratio, cam design, etc. A comparison between engines used in passenger cars and medium duty trucks for each of the major manufacturers is given in Appendix A-1. In general, most of the engines identified in Table 2.2 have direct counterparts in the light-duty vehicles. Except for a few cases, these engines are identical internally with the same camshafts, heads and compression ratios. For the 1973 model year, the medium-duty engines are equipped with fewer external control devices for emissions and are rated at slightly higher horsepower levels.

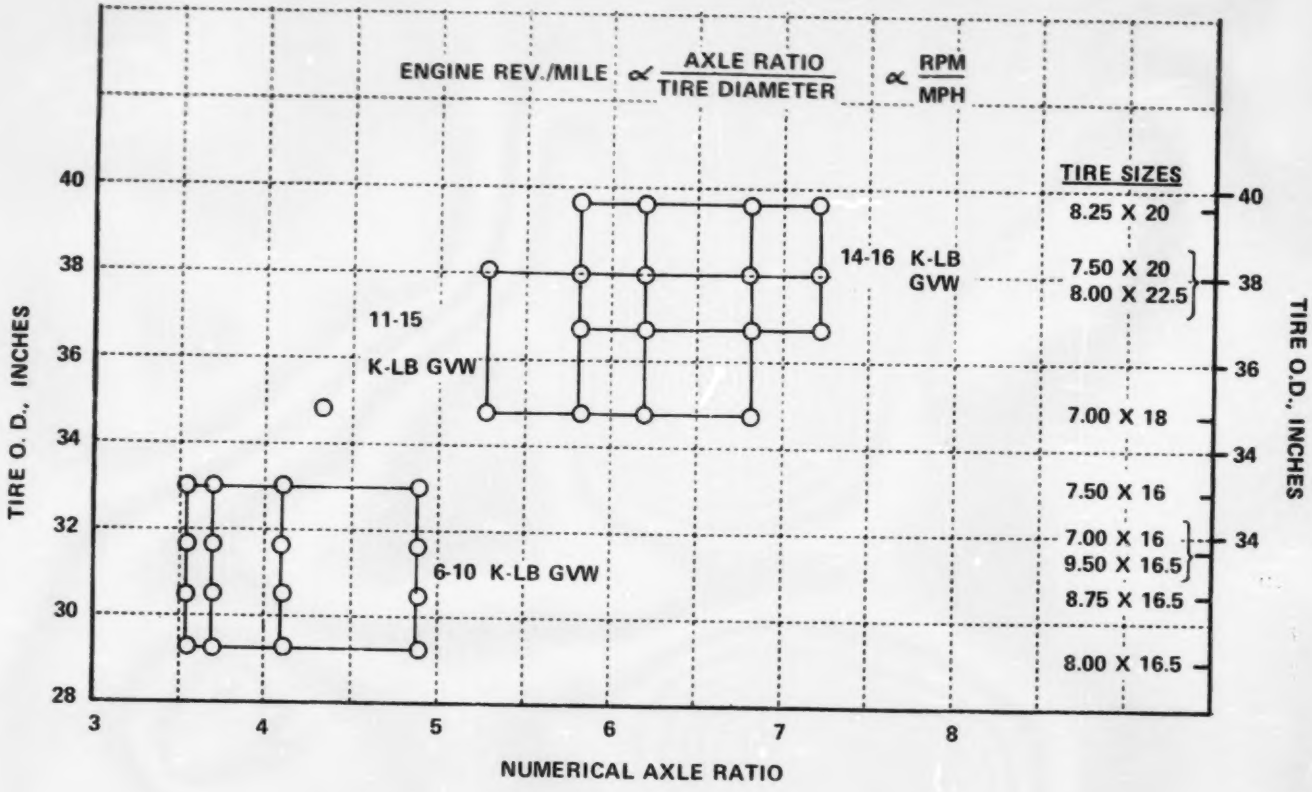
Transmission and axle ratio information presented in Table 2.2 represents the most popular (by sales) combination for each vehicle model and engine combination. In cases where such data were not provided by the manufacturer, an estimate was made based on a comparison with other comparable models. Axle-ratio options for the medium-duty trucks overlap those available for light-duty vehicles to a small degree. Reflecting higher vehicle weights, the MDV generally use a higher ratio axle.

There appears to be a trend toward the use of automatic transmissions in vehicles which use the larger CID engine options. Motor home units are all equipped with automatic transmissions to promote ease of driving. Large CID engines are common in motor home applications and reflect the need for additional power to achieve acceptable performance with the high GVW ranges of these vehicles.

A vehicle parameter found to be useful by the manufacturers is the ratio N/V (engine rpm per vehicle mile per hour). Other factors being equal for a given vehicle, it would be anticipated that a significant change in this ratio would have a pronounced effect on baseline emissions (as well as vehicle performance). Comparable information is presented in Figure 2.3 which graphically shows the relationship among tire diameter, axle ratio and GVW. As indicated in the figure, dividing the axle ratio by the tire diameter gives a number proportional to N/V. A rectangle is drawn bounding the available tire diameter and axle ratio combinations within a given GVW range. The variation in engine revolutions per mile within any one weight group can be substantial (about 38% in the 6,000 - 10,000 lb. GVW range). Significant is the fact that the 6,000 - 10,000 lb. grouping is fully isolated from both the 11,000 - 15,000 lb. and 14,000 - 16,000 lb. groups which show some overlap in the tire diameter - axle ratio combinations used.

2.3.3 Sales

Sales data are required in establishing vehicle populations and population trends which in turn impact on total pollutant emissions which



NOTE: BASED ON 1973 FORD MODELS.

Figure 2.3 RELATIONSHIP BETWEEN TIRE DIAMETER, AXLE RATIO, AND GVW FOR MEDIUM DUTY VEHICLES

can be attributable to these particular groups of vehicles both now and in the immediate future. A summary of factory sales for the past decade is given in Table 2.3 according to GVW. These data provide a perspective and overview of the relative ranking of the 6,000 - 10,000 lb. GVW and 10,000 - 14,000 GVW vehicle categories compared with the entire spectrum of motor vehicles classified as trucks and buses. The 6,000 - 10,000 lb. GVW group is by far the most populous if the light-duty group of trucks is excluded. There has been an essentially unbroken upward trend in the sales of this weight class of vehicle. While the sales in the 10,000 - 14,000 GVW group remained static, and at a very small fraction of the 6,000 - 10,000 GVW group, for a period of eight years, a strong surge in sales has taken place in since 1970. This effect is considered to be directly related to the rapid increase in motor home sales in this period of time.

A further breakdown of sales by body style and GVW for 1967 - 1972 is presented in Table 2.4. A summary of sales of recreational vehicles is also included. Probably the most striking feature of these data is the popularity of the pickup truck which has accounted for well over 55% of the total annual sales of the two weight groups included in Table 2.4. The market share of the multi-stop and chassis groups has been substantially stable while the van group has captured a steadily rising share of the sales (3% in 1967 to 14% in 1972).

Sales data for recreational vehicles are shown over the same period of time. These figures represent considerable rounding off since they are the sums of similarly rounded monthly data. Truck campers have registered a steady growth in sales. On the other hand, motor home sales have doubled over the previous year in both 1971 and 1972. A further breakdown of motor home sales by type is given below.

	Conventional	Van	Chopped Van
1971	37,795	9,457	12,732
1972	64,600	23,800	28,400

Table 2.3

Factory Sales of Trucks and Buses by G. V. W.

Total	6,000 & Less	6,001-10,000	10,001-14,000	14,001-16,000	16,001-19,500	19,501-26,000	26,001-33,000	Over 33,000	Total
1962	677,804	213,050	8,503	27,495	142,163	93,138	35,153	42,862	1,240,168
1963	836,129	246,650	5,679	28,450	145,298	109,570	32,186	58,746	1,462,708
1964	919,663	250,204	5,804	24,234	142,277	104,499	29,613	64,159	1,540,453
1965	1,058,211	294,178	5,020	25,751	144,449	109,625	39,968	74,603	1,751,805
1966	1,020,158	296,957	7,485	21,286	125,473	124,361	44,337	91,027	1,731,084
1967	899,986	289,835	5,207	16,499	88,213	123,934	37,960	77,828	1,539,462
1968	1,136,059	385,803	4,646	17,495	79,436	141,264	41,814	89,561	1,896,078
1969	1,121,222	405,108	7,161	13,491	78,105	147,405	33,304	117,383	1,923,179
1970	950,252	401,592	7,353	9,979	59,205	124,554	38,451	101,054	1,692,440
1971	1,196,544	444,052	16,007	14,871	58,042	132,197	36,441	110,735	2,053,146
1972	1,414,551	539,052	43,989	9,945	28,080	182,058	42,213	141,127	2,446,807

Source: MVMA

TABLE 2.4 ANNUAL U. S. DOMESTIC FACTORY SALES(1)

6,000-10,000 LBS. AND 10,000-14,000 LBS. GVW VEHICLES

Body Style	1973(3)	1972	1971	1970	1969	1968	1967
Pickup/Camper (6K-10K)	355,129 48.4%	345,117 59.2%	273,406 59.4%	215,431 57.4%	247,466 64.9%	256,566 70.1%	173,700 64.5%
Van/Pass. Van*/Panel (6K-10K)	75,727 10.3%	83,614 14.3%	64,048 13.9%	46,048 12.3%	13,771 3.6%	8,087 2.2%	7,379 2.7%
Multi-Stop (6K-10K)	150,993 20.6%	23,339 4.0%	33,612 7.3%	32,431 8.6%	38,126 10.0%	27,141 7.4%	25,969 9.6%
(10K-14K)(2)		41,528 7.1%	16,007 3.5%	3,376 0.9%	4,183 1.1%	1,915 0.5%	2,582 1.0%
Chassis (6K-10K) (Cab, Cowl, Bare)	151,316 20.6%	87,432 15.0%	72,966 15.8%	74,221 19.8%	74,978 19.7%	69,682 19.0%	59,768 22.2%
(10K-14K)		2,370 0.5%	NA --	3,977 1.1%	2,978 0.8%	2,661 0.7%	NA --
Totals(4)	733,165	583,400	460,039	375,484	381,502	366,052	269,398

RECREATIONAL VEHICLES(5)

	1973(3)	1972	1971	1970	1969	1968	1967
Truck Camper		110,000	107,200	95,900	92,500	79,500	61,600
Motor Home		116,800	57,200	30,300	23,100	13,200	9,050

Note: Motor Homes are included in the multi-stop and chassis groups

(1) MVMA FS-20 Summary Sheets
(2) These data are inferred
(3) Manufacturer's estimates (pickup/cab chassis data in some cases split 0.78/0.22)
(4) Subject to error due to multiple listing of a vehicle on FS-20
(5) "Recreational Vehicle Facts and Trends"

These data dramatically emphasize the importance of the truck/camper and motor home in the current sales of medium-duty trucks. Since the majority of the campers and essentially all of the motor homes have a GVW in the 6,000 - 14,000 lb. range, it is seen that in 1972 40% of the medium-duty truck sales were accounted for by the recreational vehicle. This figure may be high since some of the demountable camper units may have been purchased for retrofitting to other than new trucks. Nevertheless, even discounting for this possibility, the percentage will still be high.

Sales projections for 1973 represent the sum of the manufacturers' own estimates and combine data from Chrysler, Ford, General Motors, and International Harvester (no data were provided by Ford for motor home chassis sales projections). In a number of cases, the sales projections supplied by a company were for models which included both pickup and chassis-type body styles. In these cases, the composite sales data were apportioned as follows: pickup 78% and chassis 22%. This ratio appeared to be consistent with similar data from other manufacturers whose sales were given by individual body style. This mix is probably not constant from one company's sales to another and may account for the rather low share of the market assigned to pickups for 1973 (see Table 2.4).

Manufacturers projected sales for their medium-duty truck engines for 1973 were obtained and are summarized in Table 2.5. The data are aggregated according to four general classifications: (1) sixes, (2) small eights, (3) intermediate eights, and (4) large eights. While sales data for individual engine families for each manufacturer were furnished, the format of Table 2.5 is used to preserve the confidential nature of these data in accord with the manufacturers' requests.

TABLE 2.5

Projected 1973 Sales of Medium Duty Truck Engines

Engine Classification	CID	Sales
Sixes	225-300	44,000
Small Eights	302-318	100,000
Intermediate Eights	330-360	498,000
Large Eights	390-454	100,000

Intermediate-sized eight cylinder engines are seen to be the most popular for the medium duty truck group by a large margin. The bulk of the sales in this engine group are attributable to the 350 and 360 CID engines made by General Motors and Ford, respectively. Six-cylinder engines are seen to be a minor factor.

A graphical summary of vehicle sales, past and future, is shown in Figure 2.4. Separate sales curves are given for all vehicles in the range of 6,000 - 10,000 lbs. GVW and 10,000 - 14,000 GVW. A rapid upturn in sales has taken place in both weight categories starting in 1970. A composite curve of sales of all motor homes is also presented and exhibits a rapid rise starting in 1970. Sales projections through 1980 are based on an extrapolation methodology which is discussed in Section 3.0 of this report. Projections for motor home sales are especially hazardous because of a limited history of sales and the fact that we are currently in a rapidly expanding market for these vehicles. A leveling-off of sales is estimated after 1974. Motor home sales and sales of vehicles in the 10,000 - 14,000 lb. GVW category are felt to be highly correlated since the former is considered to dominate the latter.

2.3.4 Usage

Emissions levels generated by a vehicle are affected by the type of usage to which a vehicle is subjected. Factors such as load carried,

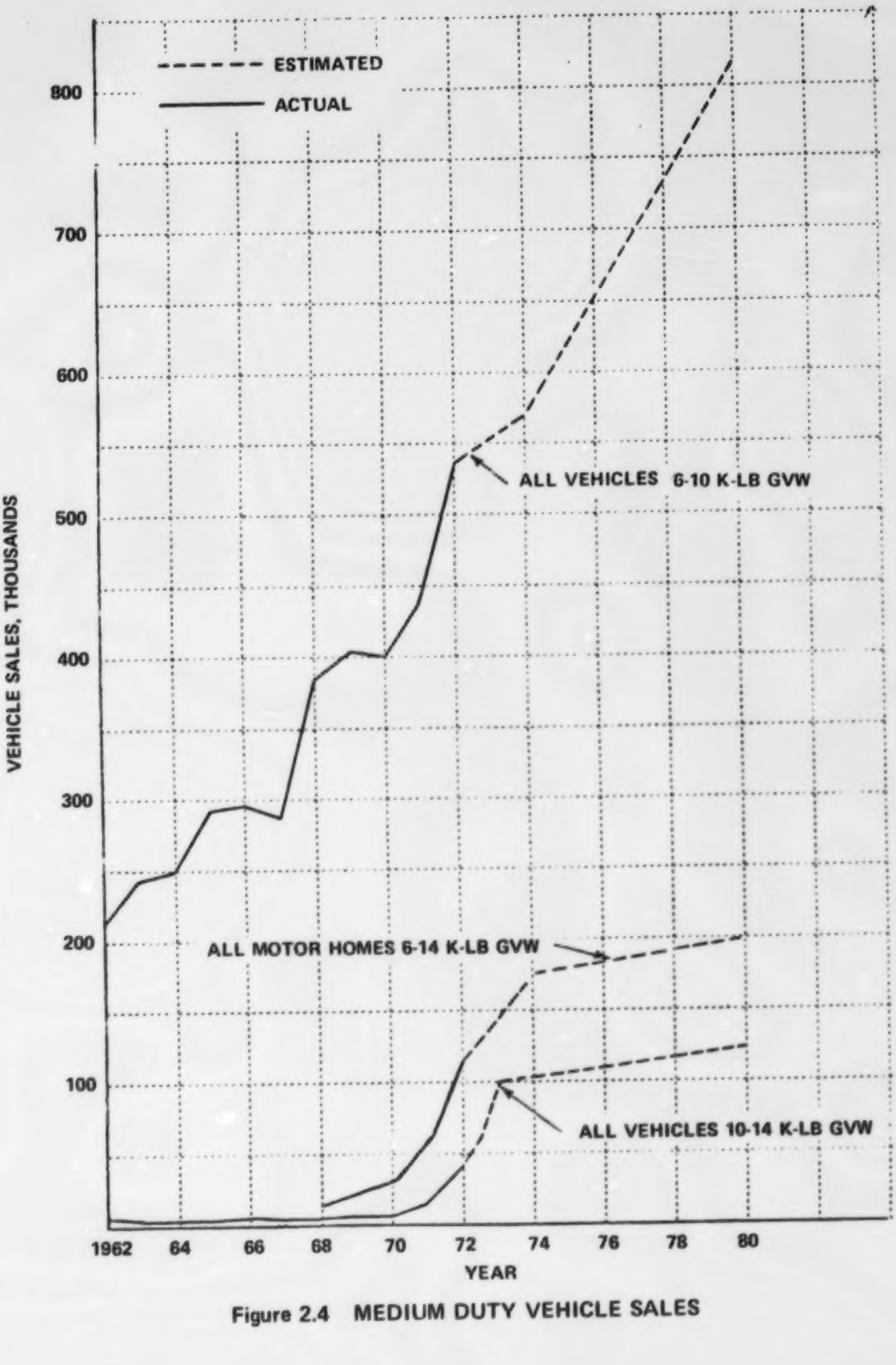


Figure 2.4 MEDIUM DUTY VEHICLE SALES

trips per day, daily mileage, route followed, etc. are all important elements in the emissions equation. In isolating vehicle types or vehicle subgroups which may have unique emissions characteristics and in validating a range of weights by which to characterize a medium-duty category of controlled vehicle, information on vehicle usage is a useful input.

A review of readily available literature, References 1-5, showed that data on the usage of vehicles in the 6,000 - 14,000 lb. GVW range are quite limited and often not directly relevant to these immediate needs. The following specific deficiencies were noted:

- vehicle classification by nonuseful GVW ranges; ie., under 10,000 lbs., 10,000 - 20,000 lbs., etc.
- use of vehicle population samples unique to specific urban areas and atypical of the national average.
- dated information (in one case a decade old) based on a non-current mix of vehicles
- limited information on daily usage by vehicle type.

A summary of the more useful findings follows.

Reference 4 is an extensive compilation of statistical survey data related to truck usage. A few significant conclusions, pertinent to this program, are drawn from that report. The study finds that the majority of motor trucks are used within an area in the immediate proximity of their home base of operations. Typically, only 2% of all trucks regularly travel more than 200 miles from the point of trip origin. Nearly 73% of all light truck movements are local as contrasted with 20% for heavy units. "Light trucks" are defined in Ref. 4 (and in most vehicular surveys) as including 2-axle, 4-tire trucks with payload capacities of one-half to one and one-half tons and with a GVW less than 10,000 lbs. The principal findings are that motor truck usage, like passenger car usage, tends to concentrate in urban areas and that there is a clear difference between light trucks and heavy trucks (GVW > 10,000 lbs.) in their usage. Light trucks are predominantly urban oriented. Based on statistics obtained by pooling survey data from 11 urban areas, the light truck accounted for (on an average daily usage basis) 72% of all truck trips, 65% of all truck miles, and 96% of all trucks employed for personal use. Of the total daily one-way trips made by light trucks, 27% were made without load. Of the trips with load, cargo was transported on 45% of the light truck trips and 28% of the trips were used to carry tools and goods related to a service function. The light truck was found to average 28 miles and 5.9 trips per day. Table 2.6 (from Ref. 4) summarizes these data and provides comparable figures for a medium-heavy truck class.

Reference 5 is a summary of a recently completed field survey of commercial vehicles in the state of California. One of the groups of vehicles surveyed was the "dual-purpose" variety as exemplified by the following types:

- pickups (including those equipped with campers, covers, and shells)
- station wagons
- small vans (including panel type and those used as house cars, mobile shops, etc.)
- truck campers (body permanently installed)
- motor homes, mobile homes and trailer coaches

Random sampling techniques were employed at 39 different locations in the state to stratify the samples geographically and functionally. Data were collected over a period of several months, over seven days of the week and during 20 hours of the day. A total of 4,938 vehicles were included in the survey (the dual-use fleet in the state is approximated as 2.5×10^6). The following synopsized features characterized the results:

- Pickups represent the largest single group of dual-use vehicles. Coupled with camper variations, they represent over half of the sample population.
- Approximately one-fourth of all pickups are equipped

Table 2.6

AVERAGE DAILY TRUCK USAGE IN 11 URBAN AREAS*

TRUCK CLASS	TRUCKS MAKING TRIPS		DAILY TRIPS		DAILY TRUCK-MILES		DAILY MILEAGE		DAILY TRIPS
	NUMBER	%	NUMBER	%	NUMBER	%	PER TRUCK	PER TRIP	PER TRUCK[1]
LIGHT ≤ 10,000 LB	72.989	71.8	608.606	67.7	2,075,660	65.3	28.4	3.4	8.3
MEDIUM-HEAVY >10,000 LB	28.691	28.2	289.810	32.3	1,104,742	34.7	36.5	3.8	10.1
TOTAL	101.680	100.0	898.410	100.0	3,180,402	100.0	31.3	3.5	8.8

*REF. 4.

[1] These values are for trucks making trips on a typical weekday. When related to all trucks registered in the urban area, the average is 5.9 trips per day, since a proportion of the registered trucks are idle on any given day.

NOTE: The values are summations of trip values for the 11 areas shown in source.

SOURCE: Comprehensive transportation studies by Wilbur Smith and Associates in Albuquerque, New Mexico; Baltimore, Maryland; Baton Rouge, Louisiana; Columbia, South Carolina; Lewiston, Maine; Little Rock, Arkansas; Manchester, New Hampshire; Monroe, Louisiana; Richmond, Virginia; Sioux Falls, South Dakota; and Winston-Salem, North Carolina.

with some sort of enclosure (camper, shell, canopy, etc.).

- Panel and van trucks represented only 8% of the sample.
- Over 85% of the vehicles were in the weight range between 3,000 and 6,000 lbs. Less than one-half percent weighed over 8,000 lbs.
- Approximately 30% of the vehicles carried no load (this figure agrees remarkably well with the 27% found by the Wilbur Smith study, Reference 4).

Usage data (trip purpose) was collected under four different headings: commuting (home-to-work), business (work related), personal business and personal (nonbusiness). Table 2.7 summarizes the results for each of several body types. Of special interest is the fact that the pickup with an equipped camper is used very frequently (49.5% of the time) for home-to-work trips. Also, the specialized nature of use of the van and panel types is demonstrated by the very high percentage of the trips that are work related.

In summarizing the results of these two reports, note must be made of the fact that trucks under 6,000 lbs. GVW dilute all of the data. Despite this, it is clear that all trucks with a GVW limit of 10,000 lbs. and less are urban oriented and act and operate in traffic very much like the typical passenger automobile. Both references agree that this group of light truck operates without load about 30% of the time. Pickup vehicles, and their variants, are predominantly used for nonwork related purposes.

The Ethyl Corporation report (Ref. 3) presents the results of a three-city survey* using trucks instrumented to record a time history of engine load (manifold pressure) and engine revolutions. Unfortunately, the entire GVW range of trucks was included within a small total sample of vehicles. Consequently the number of vehicles within the GVW range considered in this program was small and the number of different vehicle

*Detroit, Los Angeles, San Francisco

Table 2.7

Distribution by Body Type and Trip Purpose

Body Type	Percent Distribution by Trip Purposes				All Trip Purposes	
	Home-to-Work	Work-Related	Personal Business	Personal Non-Business	Percent	Number
Pickup	29.7	35.3	18.5	16.4	100	2,022
Pickup with Camper Shell	34.4	17.5	18.1	29.9	100	331
Pickup with Equipped Camper	49.5	2.9	15.4	32.2	100	382
Motor Home	28.3	1.7	25.0	45.0	100	60
Station Wagon	21.8	12.7	28.4	37.1	100	1,699
Panel	17.2	65.6	9.3	7.9	100	302
Van	1.0	90.2	2.0	6.9	100	102
Other	18.5	70.4	7.4	3.7	100	27
All Body Types - Percent	27.4	26.6	20.8	25.2	100	-
- Number	1,350	1,309	1,023	1,245	-	4,925

Source: Reference 5

types correspondingly few. Further detractions to the utility of the data result from the fact that only fleet-owned vehicles were involved and the data are quite old (vehicle models sampled ranged from 1948 to 1962). Despite these limitations the report does present data on such parameters as mean speed, daily mileage, route type and load.

An analysis of usage was made using tabulated data from Reference 3 with the objective of determining if there existed a basis for differentiating among the following GVW groups of trucks: <6,000 lbs., 6,000 - 10,000 lbs., 10,000 - 14,000 lbs. and 14,000 - 16,000 lbs. To achieve a reasonably-sized sample, the data for all three cities were pooled despite a demonstrated difference in vehicle usage among these cities. Comparisons among these groups were made for each of the following parameters: engine displacement, miles/day, percent total engine revolutions in idle, percent total engine revolutions in cruising mode, average mph and horsepower per 1,000 lb. load. Other operating modes besides idle and cruise were evaluated in the original study, but these two were selected since the largest fractions of the total vehicle operating time were spent in these two modes. For each GVW group and parameter the mean and standard deviation of the mean were calculated. The results, shown in Figure 2.5, plot the means and a vertical bar (associated with each mean) whose length represents an interval equal to two standard deviations of the mean. This type of presentation is interpreted as follows. If, by drawing a single line parallel to the horizontal axis, all four vertical bars (within any one parameter group) can be intercepted, then in a statistical sense, there is no basis for judging that any one GVW group differs from another. Stated conversely, the samples comprising each of the four GVW groups are said to originate from the same sample population. Thus, reference to Figure 2.5 shows that there is no basis for separation of vehicles by GVW within the set the data analyzed except for the last parameter, hp/1K#, which does show statistically significant differences. Since engines of the same approximate mean displacement (hence horsepower) were used in all vehicles

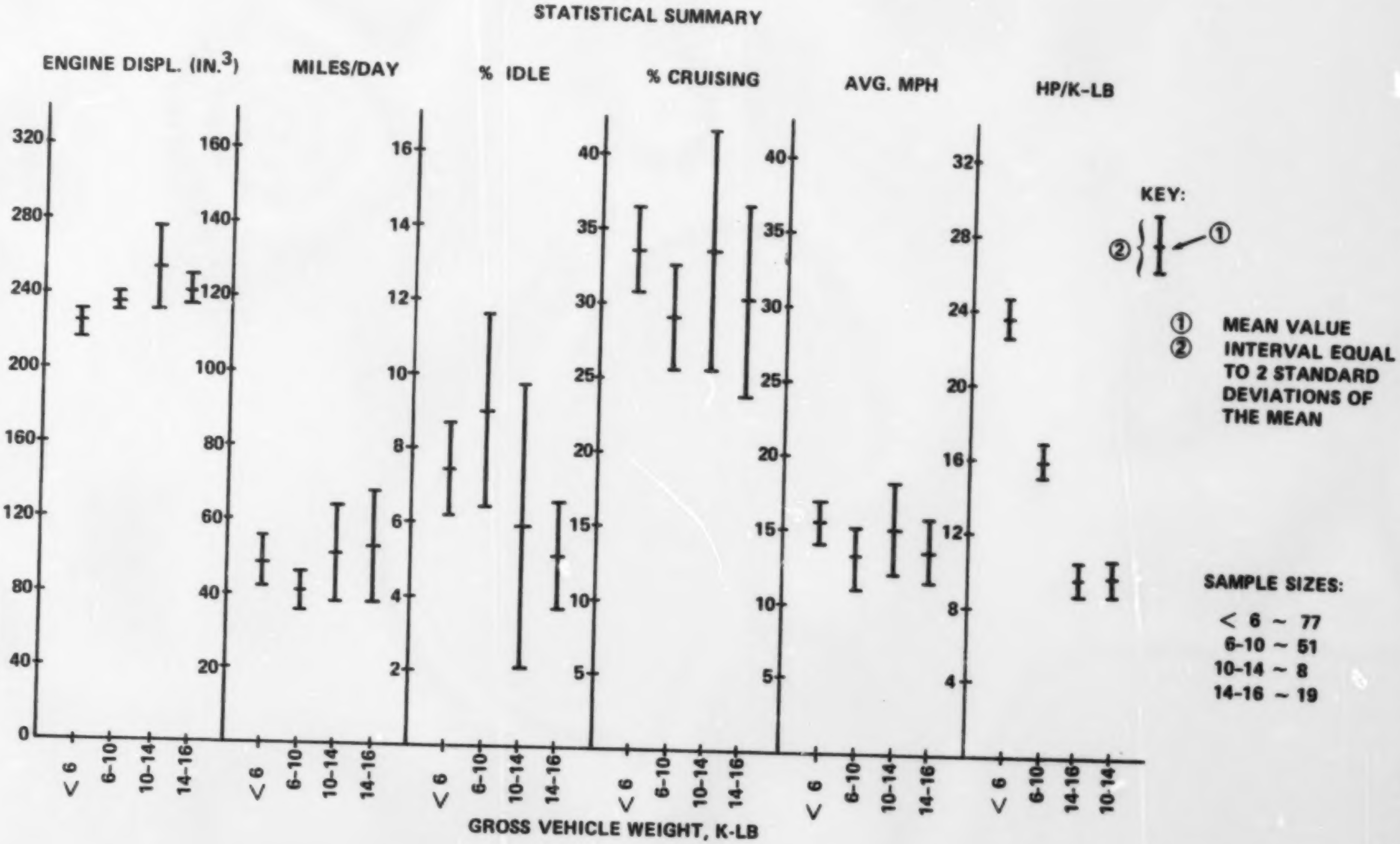


Figure 2.5 TRUCK SURVEY IN THREE CITIES*

irrespective of GVW group, these differences are not unexpected. While this finding is also not unexpected, it does verify the fact that engines used in medium duty trucks are operated at a heavier loading than those used in light duty cars or trucks. This condition obviously will need to be considered when emission controls and their effectiveness and durability in medium duty vehicles are being analyzed.

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*ETHYL CORP. REPORT GR63-24 (1963)

An analysis was made also of the relation between vehicle loaded weight and vehicle GVW (as given in Ref. 3) for vehicles up to 16,000 lbs. The data showed that all these vehicles, on the average, operated fully loaded, i.e., at GVW ratings. This result is not consistent with the Wilbur Smith study (Ref. 4) which found that "light" urban trucks operate empty 50% of the time and, when loaded, carry an average load of 600 lbs. This same study (Ref. 4) also reports that 70% of all trucks are single operations (individually owned). Several factors may explain these differences: (1) the Ethyl study, because it required the use of instrumented trucks, was forced to rely on a sample that was entirely "fleet" operated, (2) it may be inferred that the loaded weight given referred only to the value when the vehicle was operated with maximum load (i.e., no-load or part-load situations were not noted)*, and (3) differences in test locale. Data in Ref. 4 were obtained in medium-sized urban areas (see footnote to Table 2.6) whereas the Ethyl study was conducted within very large metropolitan areas.

Reference 2 is a separate Wilbur Smith report on the CAPE-21 program which to date has produced no new data but rather assembled and processed existing data on truck usage in the New York City and Los Angeles areas. All of these data are for vehicles classified only by number of axles and rear tires. For New York City, only 20% of the sample of vehicles analyzed were within the 6,000 - 14,000 GVW range. While data on number of daily trips, mean velocity and trip length were determined, these figures are unidentifiable with vehicle body types. The Los Angeles data are even less useful since the survey started with vehicles with an empty weight of 6,000 lbs. As shown in Table 2.2, it is only the rare vehicle in the 6,000 - 14,000 lb. GVW group that has an empty weight over 6,000 lbs. Consequently these references did not provide useful data.

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* Explicit information concerning the determination of vehicle loaded weight is not given in Reference 3.

2.4 Representative Vehicle/Engine Combinations

2.4.1 Selection

The selection of vehicle/engine/drivetrain combinations representative of each of the five major groups identified in Table 2.1 (pickup/camper, van/passenger van, multi-stop, chassis and motor home chassis) was performed in accord with the methodology discussed in Section 2.2. A number of considerations entered into the selection process. These included the extensiveness of usage of a particular combination, possible effects of different combinations on emissions, the need to adequately represent the GVW spectrum within any one group and the impact of these selections on the economic analysis (Part B).

In the selection process the data summarized in Table 2.2 were extensively used. This tabulation identified the vehicles according to make, model, axles, GVW range, GCW range, engine CID, horsepower, transmission and axle ratio. This table, as initially published in a project progress report (Reference 6), included the manufacturer's 1973 sales projections for each engine/drivetrain combination shown. Omission of this information in Table 2.2 is for proprietary reasons. The resultant list of group representative vehicle/engine/drivetrain combinations that were chosen is given in Table 2.7a. This listing as well as that of Table 2.1 (vehicle grouping) were subject to the approval of the EPA Project Officer.

This listing is broadly representative on several counts: (1) the largest-selling models and engines are included, (2) the range of engine displacements is adequately represented, (3) a wide GVW range is encompassed by the models selected and (4) all major manufacturers of medium duty trucks are represented.

In the multi-stop group, the selection of the Chev. /GMC P30/P35 model with a small six engine (in a high GVW vehicle) was based on a desire

TABLE 2.7a GROUP REPRESENTATIVE VEHICLE-ENGINE COMBINATIONS:

Physical Characterization - 1973 Models

GROUP	MAKE	MODEL	AXLES	ENGINE	HP	TRANS.	AXLE RATIO
Pickup/Camper	Chev./GMC	C20/C25	4x2	V8-350	155	A3	4.10
	I-H	1210	4x2	V8-345	144	M3	3.73
Van/Pass. Van	Ford	E300	4x2	V8-302	139	A3	3.73
Multi-Stop	Chev./GMC	P30/P35	4x2	I6-250	100	M4	4.56
Chassis	Chev./GMC	C20/C25	4x2	V8-454	240	A3	3.73
	Ford	F350	4x2	V8-360	148	M4	4.10
	Ford	F500	4x2	V8-330	137	M4	5.83
Motor Home Chassis	Dodge	M300/R400	4x2	V8-318	160	A3	4.88

to include a combination which might exhibit an unique emissions level due to a high engine loading.

2.4.2 Emission Controls

Emission controls, either incorporated as engine modifications or installed as add-on devices, were identified by reference to the manufacturers' certification handbooks submitted to EPA. Controls installed on 1973 models of the group representative vehicle/engine combinations (Table 2.7a) are shown in Table 2.7b. All vehicles include crankcase emission controls, however, only those vehicles marketed in the State of California are equipped with evaporative emission control systems. While all engines incorporate some types of modifications for exhaust emission control, since they generally are derivatives of light duty engines, EGR or air injection is only used on some engines sold in California. This strategy is necessary to meet the combined HC + NO_x standard of 16 gm/bhp/hr adopted by California for 1973 models. A narrative-type description of the various control systems/devices, which are only identified by their acronyms in Table 2.7b, is given in Table 2.8.

2.4.3 Baseline Emissions

In assessing the emission reductions possible by the addition of new or additional control devices to medium duty vehicles, it is necessary to define baseline emission data for each representative vehicle/engine combination as a reference.

To measure the necessary emissions data, EPA chose to test this category of vehicles using the basic 1975 Federal Test Procedure developed for light duty vehicles. In view of the usage data described in this report for the medium duty vehicle, the use of the LA-4 driving cycle for emissions determinations is justifiable and reasonable. The only variations to the 1975 FTP are found in the determination of the vehicle inertia weight and road load horsepower.

TABLE 2.7b GROUP REPRESENTATIVE VEHICLE-ENGINE COMBINATIONS:

Emission Control Devices - 1973 Models

GROUP	MAKE	MODEL	ENGINE	EMISSION CONTROLS*			NOTES
				Crankcase	Evaporative	Exhaust	
Pickup/Camper	Chev. /GMC	C20/C25	V8-350	PCV	GMECS	CCS	1
	I-H	1210	V8-345	PCV	CAN	EM, EGR, TLD	1 4 6
Van/Pass. Van	Ford	E300	V8-302	PCV	CC	IMCO	1
Multi-Stop	Chev. /GMC	P30/P35	I6-250	PCV	- -	CCS	2
Chassis	Chev. /GMC	C20/C25	V8-454	PCV	GMECS	CCS, AI	1 3
	Ford	F350	V8-360	PCV	CC	IMCO, EGR	1 4
	Ford	F500	V8-330	PCV	CC	IMCO	1
Motor Home	Dodge	M300/R400	V8-318	PCV	CAN	EM	1 5

* See Table 2.8 for description of Emission Controls.

Notes:
1 Evaporative Controls only on California vehicles with fuel tanks $\leq$ 50 gals.
2 This engine not sold in California
3 Air Injection (AI) only on California vehicles
4 Exhaust Gas Recirculation (EGR) only on California vehicles
5 Electronic Ignition on California vehicles, otherwise optional
6 Throttle Limiting Device (TLD) only on California vehicles

TABLE 2.8 - EMISSIONS CONTROL DEVICES PRESENTLY USED

Abbreviation	System Name	System Description
PCV	Positive Crankcase Ventilation System	A system which supplies fresh air to the crankcase through the air filter and directs the blow-by gases into the intake manifold through a spring-loaded metering valve.
AI	Air Injection System	A system consisting of an engine-driven air pump which supplies fresh air to nozzles located in the exhaust ports, completing combustion of hydrocarbons externally. The systems usually incorporate some flow control devices for better driveability.
EGR	Exhaust Gas Recirculation System	A system which controls oxides of nitrogen (NO_x) emissions by recirculating a portion of the exhaust gases back into the intake manifold. The plumbing consists of fixed orifices or vacuum-controlled valves.
TLD	Throttle Limiting Device	A system to limit the rate of closure of the throttle to prevent excessively high manifold vacuum during deceleration.
GMECS	General Motors Evaporative Control System	All of these systems are evaporative emissions control systems consisting basically of a charcoal or carbon filled canister into which the hydro-carbon vapors from the gas tank and carburetor are directed. They are stored here until the engine is started at which time they are purged into the intake manifold.
CC	Carbon Canister	
CAN	CANister evaporative control	
EM	Engine Modifications	These systems consist mainly of modifications and recalibrations made on basically unchanged pre-emission control engines. The carburetor and choke are modified, the spark advance curve is altered, the compression ratio is lowered, the head design is altered, a system to pre-heat intake air is installed, the camshaft profile is altered, etc.
CCS	Controlled Combustion System	
IMCO	IMproved COmbustion System	

Inertia weight rounded to the nearest 500 lbs. is obtained by the addition of a weight increment to the vehicle GCW based on the vehicle payload capacity. The weight increment is determined from the following schedule.

Payload (GVW - GCW)	Weight Increment
2000 lbs.	500 lbs.
2001 lbs. - 4000 lbs.	1000 lbs.
4001 lbs.	1500 lbs.

Road load horsepower is based on the vehicle inertia weight (I_w) and given by the following linear equation where I_w is in units of pounds.*

$$\text{Road load horsepower} = 0.0096\ I_w - 30.3$$

Emissions data provided by EPA were from three sources: (1) an EPA in-house program, (2) Southwest Research Institute (SWRI) and (3) Automotive Engineering Systems, Inc. (AESI). Data on a total of 122 vehicles were received. A tabulation of these emissions data is given in Appendix A-2. In the appendix, the information is identified according to source, vehicle make, model year, body type, GVW, GCW, inertia weight, engine and the average emissions in grams per mile for HC, CO, CO_2 and NO_x. In addition, the number of tests averaged and the state of tune of the vehicle are noted. During the early stages of these experimental programs, the vehicles were tested in an "as-received" condition, however the later groups of vehicles were tested with the engine dwell, timing and idle adjusted to specifications. Subsequent to the submittal of the draft of this report some additional emissions data were supplied by EPA. Usage of these new data in performing additional analyses requested by the Project Officer is discussed in a later part of this section.

A summary of the baseline emissions data for the selected group representative vehicle/engine combinations is shown in Table 2.9. It can be seen that for two of the categories there were no test data at all while for some others only few test points were available. Even to accumulate these meager totals it was necessary to use data from untuned and older vehicles.

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* The procedural details employed in collecting these emissions data do not necessarily represent the final test procedures that may be specified by EPA for the medium duty category of vehicles.

TABLE 2.9 GROUP REPRESENTATIVE VEHICLE-ENGINE COMBINATIONS;

Exhaust Emission Levels - Equivalent 1975 FTP

GROUP	MAKE	MODEL	ENGINE	GVW RANGE	TEST WGT. RANGE	MEAN EMISSION LEVELS (g/mi) HC	CO	NO_x	NOTES
Pickup/Camper	Chev./GMC	C20/C25	V8-350	6200-10000	5000-7500	4.57	40.57	7.81	1
	I-H	1210	V8-345	6100-7500	5000-6500	5.62	66.12	5.06	4
Van/Pass. Van	Ford	E300	V8-302	6050-7600	5000-6500	5.85	54.69	5.82	2
Multi-Stop	Chev./GMC	P30/P35	I6-250						*
Chassis	Chev./GMC	C20/C25	V8-454						*
	Ford	F350	V8-360	10,000	8200	12.85	116.28	6.93	3
	Ford	F500	V8-330						*
Motor Home	Dodge	M300/R400	V8-318	10,000 - 11,000	8,000 9,000	8.84	142.29	13.23	5

* No Test Data Available on These Engines

Notes:
1 Twelve vehicles (1-1970, 4-1971, 7-1972), average of 26 tests (25 CO)
2 Eight vehicles (2-1971, 2-1972, 4-1973), average of 16 tests
3 One vehicle (1971), average of two tests
4 Two vehicles (1-1971, 1-1972), average of two tests
5 Three vehicles (1-1970, 1-1972, 1-1973), average of eight tests

A decision was made to exclude all data from vehicles older than the 1970 models in forming baseline averages.

A review of the emissions data in Table 2.9 and all the other test data available on the medium duty trucks indicated that differences between engine/vehicle combinations could not be ascertained. The large scatter in the emissions data whether due to vehicle state of engine adjustment, vehicle mileage, vehicle age or other factors, did not permit such discrimination to be made. This statement, however, should not be interpreted to imply that no such differences exist. The data do tend to support the observation that vehicle emissions increase with the test weight (or inertia weight) of the vehicle. The limited data shown in Table 2.9 agree superficially with this contention, the chassis and motor home chassis vehicles showing, on the average, increased emissions with test weights in the 8,000-9,000 lb. range.

As a consequence of this situation, the methodology based on engine/vehicle combinations could not be pursued further. Rather, the emissions data were reviewed to ascertain what differentiation among vehicles was possible.

In making use of the emissions data base given in Appendix A-2, the following decisions were made:

- use only data from tuned 1972-1973 model vehicles if possible
- if necessary to use data from untuned vehicles, then include 1970 and 1971 models only
- exclude data from low-mileage, unstabilized (green engine) vehicles.

A serious limitation of the data base is the concentration of the data at a test weight of 5,000 to 5,500 lbs. Where data at higher test weights exist, they are almost entirely from motor homes. No data are available at a test weight exceeding 10,000 lbs.

A series of linear regressions were performed on various subsets of the data with mass emissions per mile regressed on inertia weight. A simple linear regression analysis was performed on the emissions data for all tuned 1972/1973 trucks and motor homes. A total of 40 test vehicles was available that met these criteria, 32 trucks and 8 motor homes. This sample of vehicles spanned the range of test weights from 4,500 lbs. to 8,500 lbs. with the motor homes concentrated at the upper end. Using the regression equations thus determined, emissions data were calculated at a test weight of 10,000 lbs. and compared with emissions actually measured from a few untuned and older trucks at this weight. The calculated emissions were found to be very much larger, especially for CO and NO_x levels, than the measured results. Because of the poorly distributed inertia weights, it was necessary to use a data sample that included all 1970-1973 vehicles, both tuned and untuned, to extend the range of inertia weights encompassed. Results of this analysis on a sample size of 85 vehicles indicated that the inclusion of emissions data for only nine motor homes, increased the slope of the regression lines significantly upward (compared to trucks-only data) for CO and NO_x emissions.* Consequently, a regression analysis was made for only the truck data, Results are given below.

Regression Equations - Trucks Only (76 Points)

$$M_{HC} = 0.526\ I_w + 2.38$$

$$M_{CO} = 7.09\ I_w + 19.8$$

$$M_{NO_x} = 1.02\ I_w + 1.61$$

M_i = grams/mile of pollutant i

I_w = inertia weight, thousands of lbs.

The motor homes appear to require separate consideration. Because of the small data base for motor homes (only 9 samples), a limited test weight range (7,500 -

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* It should be noted that 7 of the 9 motor homes were tested at 8500 lb. I_W or more; there were only four trucks at this same I_W included in this data set.

9,000 lbs.) and a wide scatter in the emissions data, a regression analysis was not considered justifiable. Consequently a simple average of these data was taken as the most reasonable treatment of the data that could be made. These results are shown below:

AVERAGE EMISSIONS-MOTOR HOMES (9 SAMPLES)

HC gm/mi	CO gm/mi	NO_x gm/mi	Average Test Weight lbs.
7.82	125.71	13.07	8,400

For purposes of comparison, a second set of regression equations was determined per request of the Project Officer utilizing a different data base as specified by EPA. This data base was determined in accordance with the following specific instructions:

- use all 1970 - 1973 trucks and motor homes, tuned and untuned,* excluding 1973 California (AESI) vehicles and EPA vehicle #49 (see Appendix A-2).
- treat all EPA vehicles tested at more than one inertia weight as a separate vehicle at each weight tested**
- treat all vehicles tested twice (in both tuned and untuned condition) as separate vehicles (four SWRI and nine AESI vehicles).

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* There appears to be no significant difference in measured emissions from the tuned vs. untuned vehicles for this particular data set.

** Although not shown in Appendix A-2, the first eleven EPA vehicles were each tested at four different inertia weights.

- use emission data (from 13 additional medium duty vehicles (1971 - 1973) provided by EPA (not shown in Appendix A-2).

The regression equations for this data set are given below:

REGRESSION EQUATIONS-TRUCKS AND MOTOR HOMES[*]

(135 samples)

$$M_{HC} = 0.555\, I_w + 1.94$$
$$M_{CO} = 11.20\, I_w - 8.19$$
$$M_{NO_x} = 1.35\, I_w - 0.56$$

A plot of the two sets of regression lines for HC, CO and NO_x emissions for trucks alone and trucks/motor homes combined is shown in Figures 2.7 through 2.9. Included for the trucks/motor homes regression lines are the 95% confidence limit bounds.[**] Plots of the baseline emission data vs. inertia weight are included in Appendix A-9.

The reduction of exhaust emissions through the application of control technology/alternate engines to the medium duty group of vehicles is considered in Section 2.6. Control of evaporative emissions in this category of vehicle is straightforward and is already being implemented in 1973 vehicles being sold in the state of California. A discussion of evaporative emission is included in Appendix A-3, "Evaporative Emissions."

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[*] These equations were generated after completion of the project and were not used in the analysis.

[**] The probability that the true regression line lies within the area bounded by the confidence limit curves is 0.95.

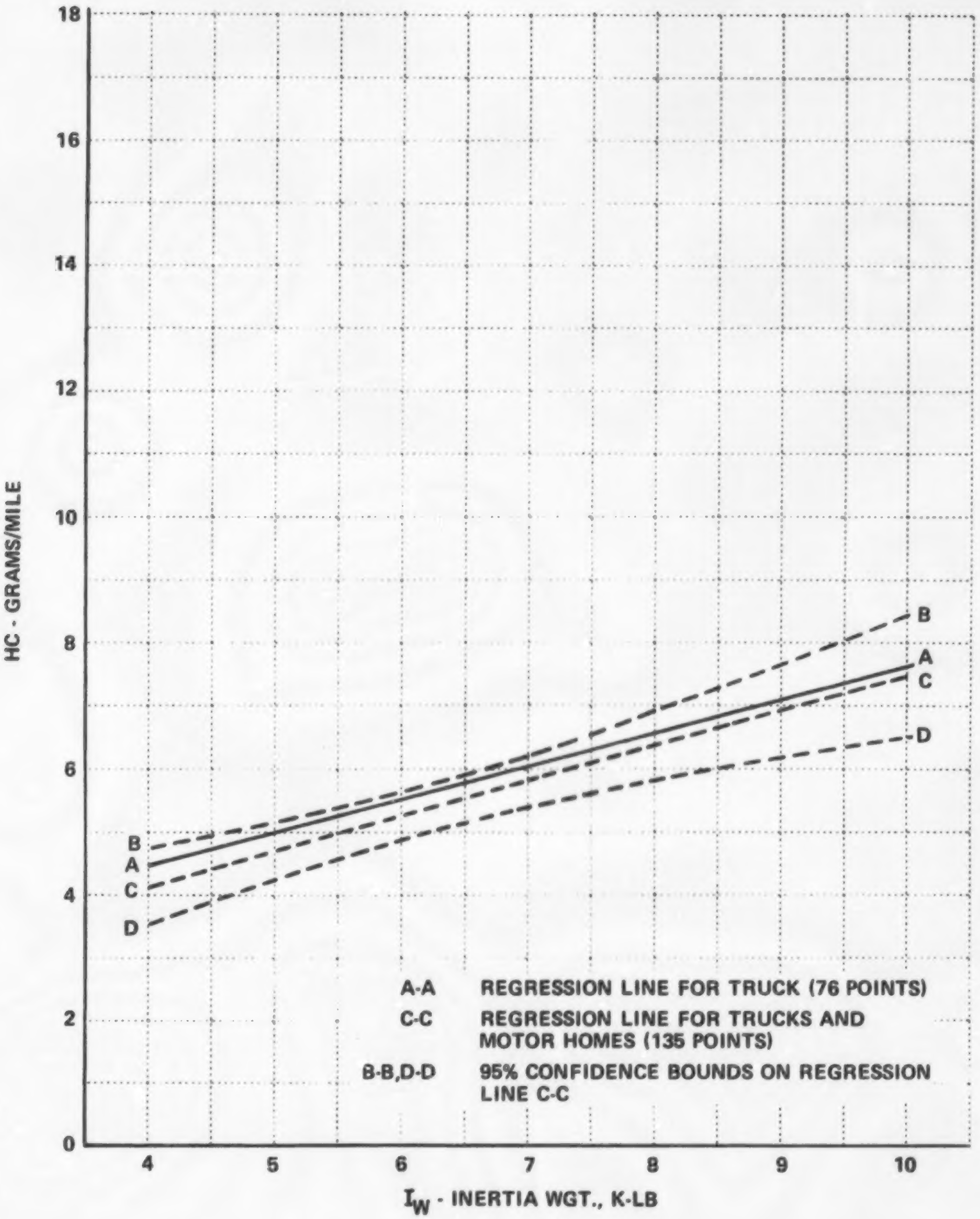

Figure 2.7 REGRESSION LINES OF HC EMISSIONS ON INERTIA WEIGHT FOR TRUCKS AND TRUCKS/MOTOR HOMES COMBINED

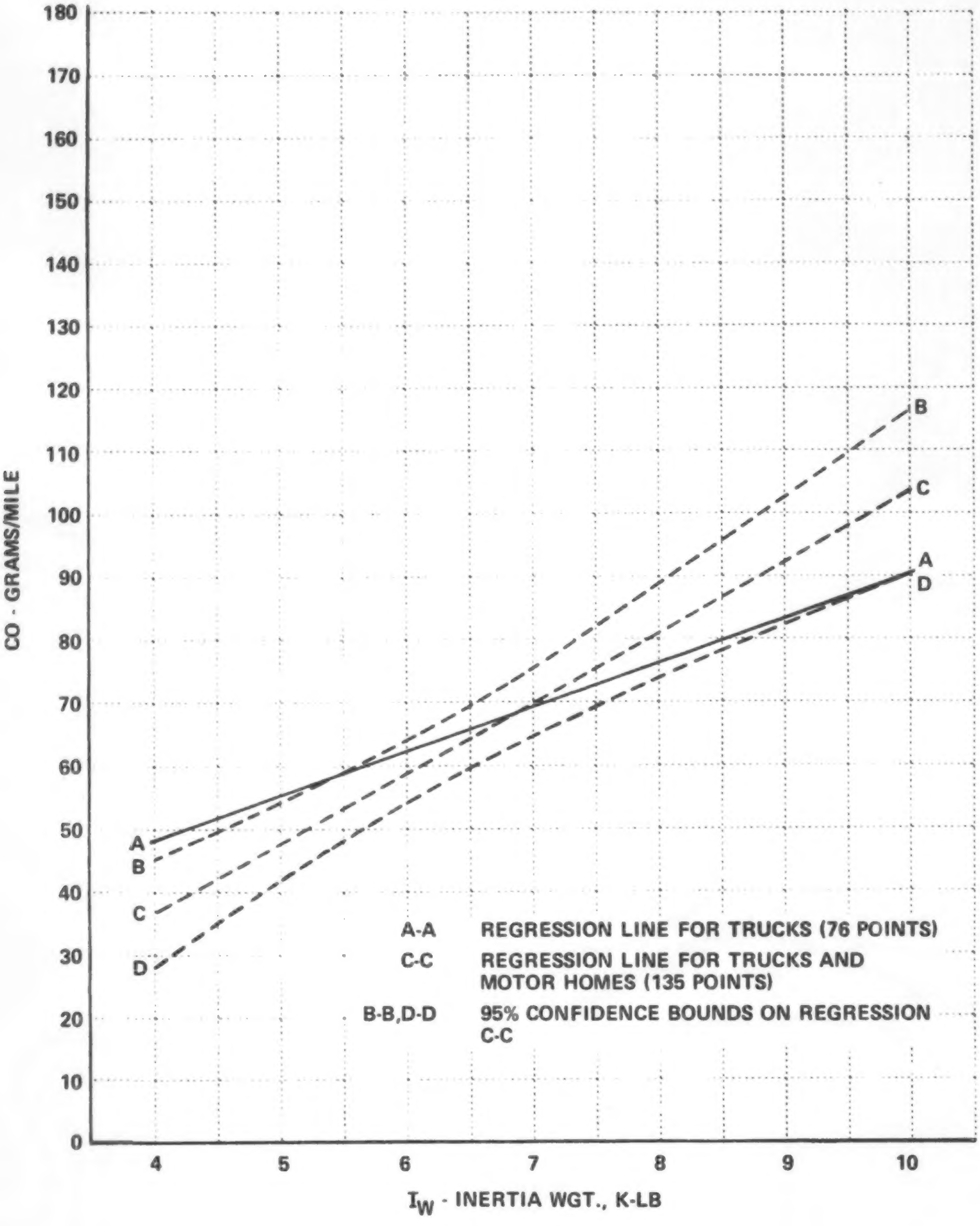

Figure 2.8 REGRESSION LINES OF CO EMISSIONS ON INERTIA WEIGHT FOR TRUCKS AND TRUCKS/MOTOR HOMES COMBINED

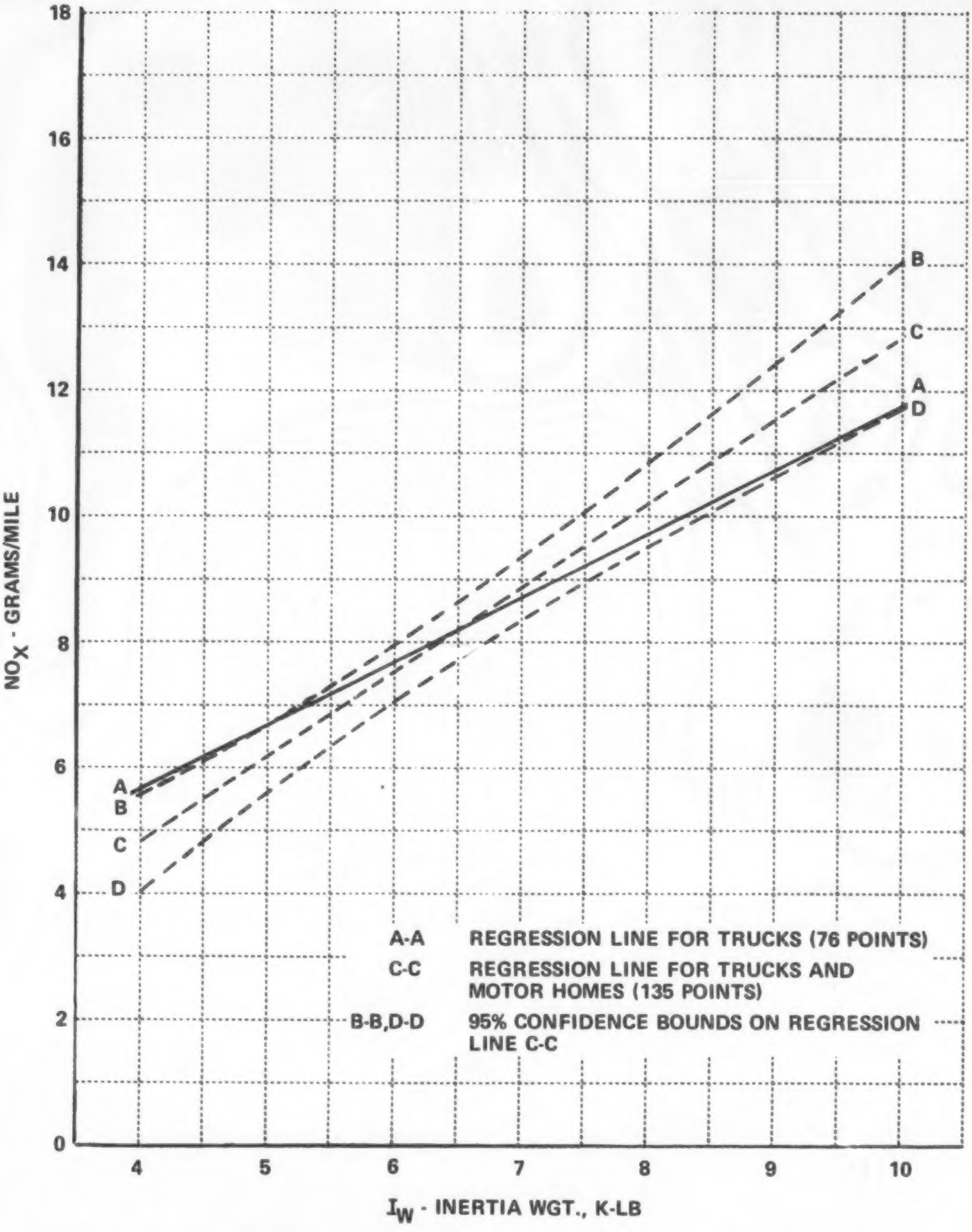

Figure 2.9 REGRESSION LINES OF NO_X EMISSIONS ON INERTIA WEIGHT FOR TRUCKS AND TRUCKS/MOTOR HOMES COMBINED

2.5 Validation of GVW Limits

The results of the studies concerned with vehicle mechanical aspects, usage, sales and emissions, which have been discussed in the preceding sections of this report, provide a basis upon which a selection of suitable GVW limits for a controlled category of medium duty vehicle can be considered.

This project was initiated with two explicit assumptions (as incorporated in its statement of work): (1) an equivalent 1975 FTP would be used in measuring exhaust emissions from the MDV group and (2) emission control technology from the LDV category was directly adaptable to the MDV group and an analytical prediction of potential emissions reduction thereby possible was feasible. Implicit in these assumptions is the appropriateness of the LA-4 driving cycle in reflecting usage of the MDV and the similarity in engines/transmissions/axle ratios between the LDV and MDV. In selecting limits therefore, every effort should be made to insure that the validity of these assumptions is reinforced to the maximum extent consistent with other restraints.

A basis for making judgments on the GVW limits exists in terms of the following four aspects of the vehicles included in the medium duty category: population, physical characteristics, usage and emissions. A simplification among the vehicle types included in this category is readily made. Usage information and emissions data both identify the motor home as a unique member of the medium duty group of vehicles. Since it must be accorded special consideration, its role in influencing GVW limits for the general group of medium duty vehicles can be considered minimal.

Consider the lower limit of the GVW range of a medium duty category. One possibility admits of the extension of the light duty class of vehicle to include a GVW range in excess of the present limit of 6,000 lbs. Two factors rule strongly against this approach. First, the 6,000 lb. level of GVW has been shown earlier to be a sort of watershed level at which certain vehicle models reach their maximum weight ratings and others begin with their minimum ratings. In the case of 1973 models, only one model vehicle, in fact, was found to violate the 6,000 lb. GVW "barrier". This factor is important in the certification process if given models of vehicles are to avoid certification under two different procedures. Once this barrier is broached, the next reasonable limit is 10,000 lbs. Second, the emissions data are seen to be a function of vehicle weight. Thus major revisions to emission standards applicable to this "expanded" LDV category would be required. Both these considerations would appear to offer serious disadvantages to any alteration of the weight limits of the light duty vehicle category. Consequently, it is concluded that the lower limit of the medium duty class of vehicle should be set at 6,000 lbs. GVW.

Factors affecting the selection of an upper GVW limit do not provide a basis that leads clearly to a single choice. Looked at from the standpoint of GVW ranges of individual models, two alternatives appear to be reasonable; 10,000 lbs. and 14,000 lbs. Based on 1973 models, only one vehicle model spans the 10,000 lb. level while several broach the 14,000 lb. limit.

Usage data, with the limited scope, do not lead to any discrimination between trucks in the 6,000 to 10,000 lb. group and those in the 10,000 to 14,000 lb. group. On the other hand, dual-purpose vehicles[*], such as pickups, vans, passenger vans, are entirely located within the 6,000 - 10,000 lb. GVW range. Dual-purpose vehicles would obviously be used and operated much more like passenger cars than purely commercial vehicles. It would also be granted that the 6,000 - 10,000 lb. GVW vehicle is more closely akin the LDV than is the 10,000 - 14,000 lb. vehicle.

Sales data clearly show the preponderant domination of the 6,000 - 10,000 lb. group. While sales in the 10,000 - 14,000 lb. group have shown large increases in the last several years, the evidence attributes this growth to motor homes alone. Thus a relatively small number of additional trucks would be included if the upper GVW limit were extended to 14,000 lbs.

The evidence is felt to favor the choice of 10,000 lbs. GVW as an upper limit for the medium duty group of vehicles. An important advantage accruing from this limit is the flexibility afforded in setting emission standards. Because of this relatively restricted GVW range, it becomes feasible to consider setting a single numerical standard for each pollutant for this class vehicle. For example, the standards could be set based on the emissions performance achievable by vehicles at the upper end of the GVW range with the presumption that the lighter vehicles would at least meet, or improve upon, these values.

Clearly, there is no compelling evidence why the GVW limit should not be set at 14,000 lbs. One result would be that vehicles less like those in the LDV category would be included and a graduated or, possibly, a two-tier emission standard would be required because of the extended weight range. Very few emission data points are presently available upon which an assessment of emission levels could be made for vehicles in the 10,000 - 14,000 GVW range.

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[*] Currently classified in the heavy duty category

The population of motor homes is less stratified by weight than it is for trucks. Sales data and projections indicate a popularity of the 10,000 - 14,000 lbs. GVW motor home that cannot be ignored. Accordingly the GVW limits for motor homes should include the range from 6,000 to 14,000 lbs. Because the motor home (1) is not used in urban areas or central business districts (2) is driven only about 5,000 miles per year (RVI publications) as compared with 10,000 miles per year for medium duty trucks (Reference 1) and (3) exists in considerably fewer numbers than the medium duty truck, a less demanding emission control strategy may be considered. For example, a single emission standard could be used for all motor homes irrespective of weight over the 6,000 - 14,000 lb. range. This standard would need to be set to accommodate the vehicles at the high end of the GVW range.

2.6 Emission Reduction Potential

There are two essentially different approaches that can be followed to reduce exhaust emissions from medium duty trucks. One approach involves modifications of the conventional gasoline engine and/or treatment of its exhaust products using one of a number of emission control systems. The second approach is to replace the conventional gasoline engine with another power plant, such as the diesel or three-valve carbureted pre-chamber (CVCC) engine, which has lower baseline emissions and may or may not require an emission control system in order to meet specified emissions standards. Each of these approaches to reducing emissions from medium duty trucks is discussed in the following sections.

2.6.1 General Approaches for Reducing Medium Duty Truck Emissions

2.6.1.1 Reduction of Emissions from Conventional Gasoline Engines

The HC and CO exhaust emissions from the conventional gasoline engine used in most medium duty trucks have been significantly reduced over the past five years by a series of engine modifications including timing changes, carburetor A/F ratio changes (leaning), cylinder piston and head shape changes, and a compression ratio reduction. These modifications have also occurred in truck engines because essentially the same engines are used in trucks as passenger cars for which federal emissions standards have been progressively tightened since 1968. The baseline engines for the present truck study are those used in 1972-73 trucks outside of California (i.e., no EGR). The corresponding baseline emissions are those from trucks using the baseline engines. Correlations of the baseline emissions as a function of truck inertia weight have been previously discussed in Section 2.4.3. Emissions control systems (further engine modifications and exhaust gas treatment devices) are applied to the baseline engines and their effectiveness referred to the baseline emissions.

The emissions control systems to be evaluated for medium duty truck applications are listed in Table 2. 10. The various components in the control systems for gasoline engines are identified and described briefly in Appendix A-4. The systems chosen for the most part have been developed and tested to a reasonable extent for light duty vehicle applications. They offer as a group the capability of achieving a wide range of emissions reductions. This was necessary in the present study because emissions standards for medium duty trucks have not been set and it was desired to investigate in detail the emissions reductions/cost tradeoffs of a cross-section of control systems. In later sections, the emissions reductions that can be expected using each of these systems on conventional gasoline engines are studied as well as the effects of the control system on fuel consumption and vehicle driveability.

2. 6. 1. 2 Alternative engines

The exhaust emissions from medium duty trucks can also be reduced by replacing the conventional gasoline I. C. engine with a power plant with lower baseline emissions. As indicated in Table 2. 12, a variety of power plants are being developed which could be considered for use in MDV. These power plants vary widely in their status-of-development and cost, size, and fuel consumption relative to the gasoline engine which they would replace. In the present study, the only alternative power plants considered were the light weight diesel and the three-valve carbureted pre-chamber (CVCC) engines. Both of these engines have attractive HC and CO emissions and fuel economy characteristics. In addition, the NO_x emissions of each can be reduced to a relatively low level (1-1.5 gm/mi) using EGR. The gas turbine engine was not included because in its present design it has a high NO_x emission level (3-4 gm/mi) and poor fuel economy at part-load conditions which are regularly

Table 2.10: Emission Control Systems for Conventional Gasoline I.C. Engines

Number	System
0	EM°(a)
1	EM° + EI + FC + AI + EGR
2	EM° + EI + IC + QHI + AI + EGR
3	EM° + EI + IC + QHI + EGR + AI + OC
4	EM° + EI + IC + QHI + EGR + RC + AI/CAI + OC
5	EM° + EI + EFIC + EGR + RC/OC
6	EM° + EI + IC + QHI + EGR + LTR
7	EM° + EI + FC + EGR + AI + RTR
8	EM° + EI + FIC + IQHI + AI + EGR

(a) 1972 engine modifications included in the baseline engine configuration

Component Identification

EI - Electronic Ignition
FC - Fast Choke
QHI - Quick Heat Intake
AI - Exhaust Manifold Air Injection
EGR - Exhaust Gas Recirculation
IC - Improved Carburetion
CAI - Air Injection Ahead of Catalyst
OC - Oxidizing Catalyst
RC - Reducing Catalyst
AI/CAI - Controlled Air Injection
EFIC - Electronic Fuel Injection and Control
RC/OC - Three-way Catalyst
LTR - Lean Thermal Reactor
RTR - Rich Thermal Reactor
FIC - Further Improved Carburetion
IQHI - Improved Quick Heat Intake

Table 2.11: Control System Configurations

Code Letter	Engine	Control Combinations
A	I-6, CID 250	1-8
B	V-8, CID 318	1-8
C	V-8, CID 360	1-8
D	V-8, CID 454	1-6, 8

Reactor Volumes and Configurations

Catalytic Reactors

Engine	No. of Oxid. Catalyst	Total Vol. of OC (in ^{3})	No. of RC	Total Vol. in RC (in ^{3})
A	1	150*	1	200*
B	1	225	2	250
C	1	225	2	250
D	2	300	2	300

All catalysts used with low lead gas ($< .05$ gm/gal) and they must be replaced every 25,000 miles.

Thermal Reactors

Engine	No. of Reactors	Total Vol. (in ^{3})
A	1	200**
B	2	240
C	2	270
D	Not applicable	

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* Pellet, noble metal type (about 2/3 this size if monolith used).

**Reactor volume is 75% of CID. This could vary between 70% and 100% of CID depending on design.

Table 2.12: Pollution, Cost, and Fuel Consumption Characteristics of Alternative Automotive Propulsion Systems

Propulsion System	Pollution[a]			Cost[b]	Fuel Consumption	Ref[c]
	HC	CO	NO_x			
Spark Ignition						
w/o controls[d]	6	6	10	1	1	8
with controls	1	1	1	1.25	1.12	10
CVCC (w/o controls)	1	1	3	1.25	.9 - 1.1	34, 35
Diesel (pre-chmaber)						
w/o EGR	.3	.25	6	1.5-2	.65	27
with EGR	.3	.7	3.0	1.5-2	.65	27
Rankine Cycle	1	.5	4[e]	2-3	1.25-1.5	40
Gas Turbine	1	1	8[e]	1.5-2.5	1.0-1.5	40
Stirling	.25	.1	.5	1.5-2	.67	40

a - relative to 1976 Emission Standards

b - relative to the conventional gasoline engine

c - numbers refer to list of references (Section 4.0)

d - w/o controls refers to reference 1972 vehicles

e - present designs, advanced versions will have NO_x emissions closer to 1976 standards encountered in urban driving. Reduction of the NO_x emissions from the gas turbine requires significant modifications of the combustor design.(7)

2.6.2 Conventional Gasoline Engines

In this section the potential for reducing HC, CO, NO_x emissions from medium duty trucks using the various control systems listed in Table 2.10 is discussed in detail. Methods are presented for determining the exhaust emissions from trucks using specified control systems. This can be done once the baseline emissions from the truck and the following information characterizing the effectiveness of the control system are known:

1. Mean reduction factors.
2. Standard deviation of the reduced emissions when the system is used on a large number of trucks.
3. Mean deterioration factor between 4,000 and 50,000 miles.

Information concerning the effect of the control system on vehicle driveability and fuel consumption is also needed to assess the influence of the control system on the truck operation. The information needed to characterize the control systems is available for light duty vehicles (GVW less than 6,000 lbs) but very little is available pertinent to medium duty trucks (GVW between 6,000 and 14,000 lbs). Hence light duty vehicle data must necessarily be used extensively in characterizing the various control systems used on medium duty trucks.

The following general approach was taken in adapting the light duty vehicle results to medium duty trucks. First, the control effectiveness (fractional reduction in HC, CO, NO_x emissions relative to a baseline level) of each system when used on standard-sized passenger cars (4500-5000 lbs) was determined from emissions data obtained by the automobile industry and their suppliers during the course of emission control system development and evaluation programs for LDV. Second, it was assumed that for each system the same effectiveness could be achieved for MDV applications after the system had been suitably developed to meet the specific needs/conditions of the truck applications. Third, when the limited truck chassis dynamometer and engine emissions mapping data permitted, the reasonableness of the predicted MDV control system effectiveness factors was assessed. The important topic of the differences between the control of emissions from light duty and medium duty vehicles is discussed in considerable length in Section 2.6.2.4-5.

2.6.2.1 Emission System Control Effectiveness Factors

As stated previously, it was assumed that the control effectiveness information available for passenger cars could be adapted to truck applications when expressed in terms of a reduction factor. As in the case of the trucks, the baseline engine/vehicle configuration used for light duty vehicles in the present study was that of 1972 (outside California). The corresponding baseline emissions[*] (gm/mi) are:

HC - 1.7 ± .63
CO - 16.5 ± 6
NO_x - 4 ± 1

where the uncertainity is effectively the standard deviation. This means that the emissions of 68% of the cars fall within the range indicated or that 95% fall within the average $\pm 2\sigma$. The baseline emissions[**] for HC and CO were obtained from the 1972 light duty vehicle certification results given in Reference (8), while the NO_x baseline emission level was taken from the GM production audit results listed in Table 2.13.

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[*] All emissions results given in this report are for the 1975 CVS-CH test procedure. 1972 CVS-C data are converted to 1975 CVS-CH results as follows: 1975 HC = 1972 HC/1.13; 1975 CO = 1972 CO/1.39; 1975 NO = 1972 NO.

[**] Based on 25 randomly selected GM, Ford and Chrysler vehicles having inertia weights of 4000 - 5000 pounds.

Table 2. 13 Engine Emissions at Low Mileage: Mean and Standard Deviation(13)

	Emissions in grams/mile[a]					
	HC		CO		NO_x	
	mean	(S. D.)	mean	(S. D.)	mean	(S. D.)
GM 1972 production[b] audit	1.7	(0.64)	22	(8.3)	4	(1)[c]
Best GM division 1972 production	1.2	(0.32)	16	(6.2)	4	(1)[c]
Potential[d] best engine emissions, lean carburetion	1	(0.15)	10	(3)	2.5	
Potential best[e] engine emissions, rich carburetion	1.5		25		1.5	

---

[a] 1972 CVS-C test procedure

[b] 3656 vehicles tested

[c] California 7-mode test emissions multiplied by 2

[d] Standard-size car, with quick heat manifold, improved carburetor, quick acting choke, and EGR

[e] Same as (d) and with air injection injection into the exhaust manifold

Reduction factors are determined by dividing the vehicle emissions obtained with a given control system by the mean baseline value. The reduction factor R is defined as:

$$R = X \pm Y$$

The quantity X is the mean reduction factor and Y^* is the uncertainity in the reduction factor due to the statistical variation in the emissions data. Y can be considered as a rough approximation of the standard deviation. In many cases, these was not a sufficient set of data to calculate a true standard deviation. The emission using the j^{th} control system can then be expressed as:

$$\overline{EM}_i^j = X\ \overline{(EM)}_i^{\circ} \qquad i = HC, CO, NO_x$$

$$(SD)_i^j = Y\ \overline{(EM)}_i^{\circ}$$

where

$\overline{EM}_i^j$ = mean emission of the i^{th} pollutant using system j

$(SD)_i^j$ = standard deviation of the emissions for the i^{th} pollutant and j^{th} system

It will be assumed that X, Y are the same for trucks and cars independent of truck weight. $\overline{(EM)}_i^{\circ}$ for the trucks will, of course, vary with weight as shown in Figures 2.7-9.

In estimating controlled truck emissions, it is also necessary to estimate deterioration factors for each system. This is difficult to do even for cars for those systems which have been tested in a large number of vehicles. Since there are no data available for the durability of control systems used on medium duty trucks, the deterioration of each system will be rated qualitatively as low, medium, or high, where each category is defined as follows:

---

* The interval about the mean which included all the data except extreme outliers was determined by scanning a compiled list of typical emissions data for each control system. Y was then calculated by dividing one-half that interval by the reference baseline value.

low	-	10% or less
medium	-	10 - 30%
high	-	30% or greater

It is assumed that the assigned deterioration would occur over 50,000 miles in the case of mechanical components and 25,000 miles in the case of catalysts.

The effectiveness of each of the control systems considered for conventional gasoline engines is discussed individually in the following paragraphs. The components listed for each system are identified and described briefly in Appendix A-4. The emissions data used to determine the reduction factor R are referenced and in most cases typical support data are included in tabular form in Appendix A-5.

System o: EM° (baseline)

The baseline system is that used in most 1972 vehicles outside of California. It consists entirely of engine modifications such as spark timing, carburetor A/F ratio, and compression ratio changes. The emissions from this system were determined from the 1972 LDV certification data(8) and the GM 1972 production audit emissions data given in Table 2.13. The reduction factors are:

	HC	CO	NO_x
R =	1 ± .375	1 ± .375	1 ± .20

Certification data indicate this system has very low deterioration.

System 1: EM° + EI + FC + AI + EGR

This emission control system is essentially* that used on most 1973 passenger cars. Its control effectiveness was determined from the 1973 LDV certification data(9). The reduction factors are:

	HC	CO	NO_x
R =	1.35 ± .30	1 ± .23	.6 ± .10

This system should show low (less than 10%) deterioration.

---

* EI is not standard equipment on most 1973 LDV but this will not have a significant effect on low mileage emissions.

System 2: EM° + EI + IC + QHI + AI + EGR

This control system is essentially that which will likely be used in LDV in 1975 (outside of California) now that interium standards have been set by EPA. The control effectiveness for this system has been determined using the GM and Ford data given in References (10, 11). Sample emissions data for this system are given in Table A-5.1.

	HC	CO	NO_x
R =	.65 ± .15	.55 ± .15	.6 ± .1

This system should show low deterioration.

System 3: EM° + EI + IC + QHI + AI + OC + EGR

This control system is that which was being developed to meet the original LDV 1975 emissions standards. Using Ford and GM pre-certification(10-12) data (Table A-5.2), the reduction factors for this system were found to be:

	HC	CO	NO_x
R =	.18 ± .05	.15 ± .03	.6 ± .10

The LDV pre-certification data (12) for this system has been analyzed by EPA(41) and it was found that the average 50,000 mile deterioration factors were 1.5, 1.5, 1.1 for HC, CO, NO_x emissions respectively.

System 4: EM° + EI + IC + QHI + EGR + AI/CAI + RC + OC

This is the control system being developed to meet the .4 gm/mi NO_x standard. There is relatively little data available for this system and no fleet testing has been done. Using the GM data (13) given in Table A-5.3, the following reduction factors are estimated:

	HC	CO	NO_x
R =	.18 ± .05	.15 ± .03	.075 ± .05

At the present time, this is a high deterioration system for NO_x emissions, but before it can be put into production this rapid deterioration for NO_x would have to be drastically improved.

System 5: EM° + EI + EFIC + EGR + RC/OC

This is the most advanced prototype catalyst system being considered for gasoline engines and is in a relatively early stage of development. Very limited emissions data are available for this system but considerable development work is currently in progress. A projection of the limited test results (Table A-5.4) indicated that the following system effectiveness can be attained:

	HC	CO	NO_x
R =	.18 ± .03	.15 ± .-25	.075 ± .025

The deterioration of this system depends on both the catalyst and O_2 sensor durability. Achieving low deterioration for this system will require considerable development work.

System 6: EM° + EI + IC + QHI + EGR + LTR

This is the system developed by the Ethyl Corporation and is termed a "Lean Thermal Reactor". It is described in detail in Reference (16). Pertinent emissions data for the LTR system are given in Table A-5.5. The estimated reduction factors are:

	HC	CO	NO_x
R =	.50 ± .07	.35 ± .05	.375 ± .05

Durability data given in Reference (16) indicates that the deterioration of this system is low.

System 7: EM° + EI + FC + EGR + AI + RTR

This is the thermal reactor system developed by Dupont(17), Esso, and GM(13) and is termed the "Rich Thermal Reactor". Typical emissions data using this system are given in Table A-5.6. The estimated reduction factors are:

	HC	CO	NO_x
R =	.08 ± .02	.35 ± .09	.17 ± .03

This should be a low deterioration system

System 8: EM° + EI + FIC + IQHI + AI + EGR

This is a system using advanced carburetion and intake air heating for which the atomized liquid fuel behaves almost as a gaseous fuel and the need for choke operation during engine warmup is eliminated. Both Ford and GM are developing such advanced, non-catalytic low emissions systems. Emissions data taken from References (10, 11) for this type of system are given in Table A-5.7. The estimated (projected) reduction factors are:

HC	CO	NO_x
R = .40 ± .07	.30 ± .05	.35 ± .05

The projected NO_x emissions reduction has been taken essentially equal to that already achieved by the LTR system. This should be a low deterioration system.

The reduction factor information for all the systems considered is summarized in Table 2. 14. Note that even though all of these reduction factors were developed from LDV emissions data, it is assumed that comparable systems in each case can be developed for truck applications with the stated control effectiveness and durability. This will undoubtedly require further development and in some cases new, but similar, components. This topic is discussed in greater detail in Section 2. 6. 2. 5. 2.

2. 6. 2. 2 The Effect of Control Systems on Fuel Consumption

The effect of each of the emissions control systems on truck fuel consumption was also investigated. The same sources of data used to estimate the emission reduction factors were surveyed to estimate the effect of the control systems on fuel consumption. In general, as indicated in Figure 2. 10, the fuel penalty associated with the emissions control system increase as the level of NO_x emission is reduced. However, the magnitude of the penalty at a given NO_x value is effected by the control method used to reduce NO_x. The various methods are given below ranked in order of increasing fuel penalty.

1. Reducing catalyst
2. Lean carburetion
3. EGR
4. Rich carburetion

There are two methods which are commonly used to determine the fuel economy for a given vehicle/engine/control system combination. One involves actual road testing of the vehicle over a specified driving route and the second involves the use(19) of vehicle mass emissions (CO_2, CO) ob-

Table 2.14 Summary of Emission Control System Reduction Factors

No.		Reduction Factors[2] $HC^{(4)}$	 $CO^{(4)}$	 $NO_x^{(4)}$	System Deterioration[3]
0	EM°[1]	1 ± .375	1 ± .375	1 ± .20	L
1.	EM° + EI + FC + AI + EGR	1.35 ± .30	1.0 ± .23	.6 ± .10	L
2.	EM° + EI + IC + QHI + AI + EGR	.65 ± .15	.55 ± .15	.6 ± .10	L
3.	EM° + EI + IC + QHI + EGR + AI + OC	.18 ± .05	.15 ± .03	.6 ± .10	M (HC, CO) L (NO_x)
4.	EM° + EI + IC + QHI + EGR + RC + AI/CAI + OC	.18 ± .05	.15 ± .03	.075 ± .05	M (HC, CO) H (NO_x)
5.	EM° + EI + EFIC + EGR + RC/OC	.18 ± .03	.15 ± .025	.075 ± .035	H
6.	EM° + EI + IC + QHI + EGR + LTR	.50 ± .09	.35 ± .05	.375 ± .05	L
7.	EM° + EI + FC + EGR + AI + RTR	.08 ± .02	.35 ± .09	.17 ± .03	L/M
8.	EM° + EI + FIC + IQHI + AI + EGR	.40 ± .07	.30 ± .05	.35 ± .05	L

(1) Baseline engine - 1972

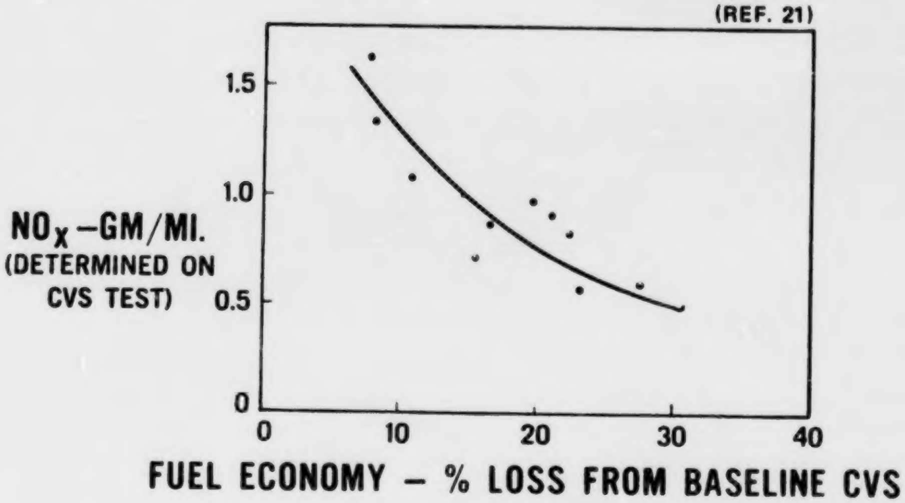
(2) System effectiveness at low mileage ($\gtrsim$4000 miles)*

(3) Deterioration of present systems; L = 10%, M = 10 - 30%, H = 30%

(4) All emissions data taken using or corrected to 1975 CVS-CH test procedure

* Based on LDV prototype systems, see pg. 2-63 for explanation.

NO$_x$ CHANGED BY VARYING FUEL, EGR AND SECONDARY AIR METERING



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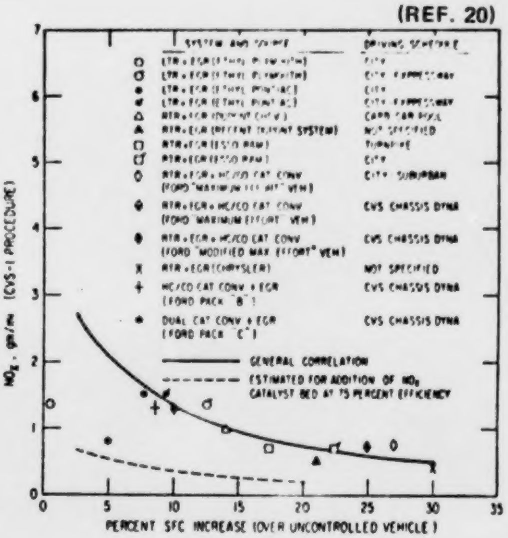


Figure 2.10 EFFECT OF NO$_x$ EMISSIONS LEVEL ON FUEL PENALTY

tained from a standard chassis dynamometer emissions test. The fuel economy experienced with a given vehicle varies significantly depending on the type of driving (city, suburban, highway, etc.) of interest. In the present study, the fuel economy results discussed correspond to city/suburban driving appropriate to the LA-4 driving cycle. It is assumed that the incremental effect (fuel penalty) of the control system can be determined equally well using the road test and chassis dynamometer approaches.

The format for expressing the fuel penalty factor FP is similar to that used for the reduction factors R - namely:

$$(FP)_j = A_j \pm a_j$$

where A_j = average fuel penalty (%) using the j^{th} system

a_j = scatter of the fuel penalty data (%) for the j^{th} system.

"a" is essentially the S. D. of the fuel economy data (MPG). As in the case of emissions, the baseline for fuel economy was taken to be 1972 model trucks. The baseline fuel economy $\overset{\circ}{Fe}$ (miles per gallon on the LA-4 driving cycle) was calculated from the (CO_2, CO) emission data for 1972-73 trucks given in Reference (18) using the following relationship$^{(19)}$ between $\overset{\circ}{Fe}$, (CO_2), (CO).

$$\overset{\circ}{Fe} = \frac{2360}{.429(CO) + .272(CO_2)}$$

where $\overset{\circ}{Fe} \sim$ MPG; (CO), $(CO_2) \sim$ gm/mi

As shown in Figure 2.11, $\overset{\circ}{Fe}$ is a function of both vehicle inertia weight and engine CID. The fuel economy for a given vehicle/engine/control system combination can be expressed as:

$$Fe = \overset{\circ}{Fe}/1 + FP$$

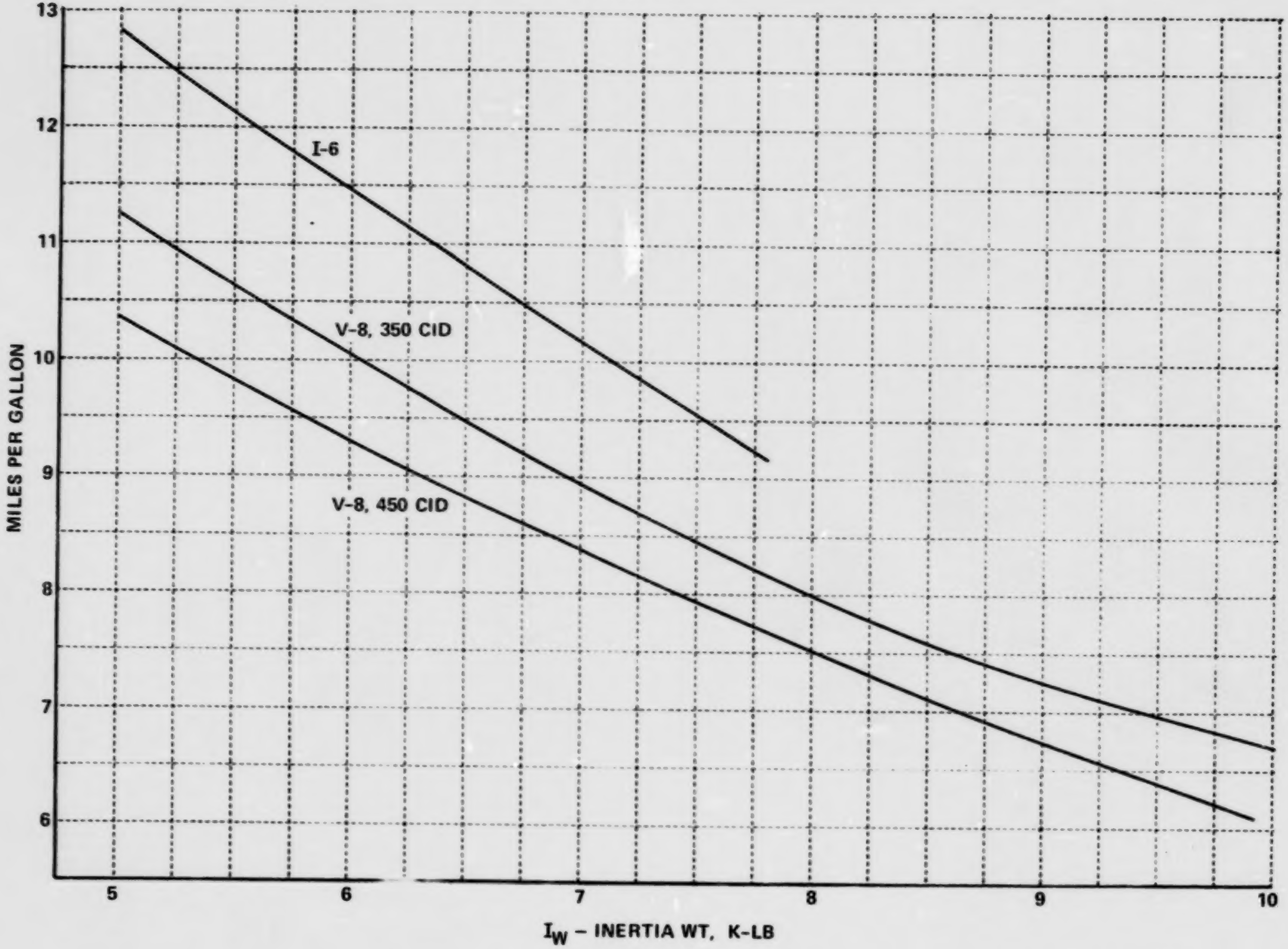


Figure 2.11 BASELINE FUEL ECONOMY (MPG) FOR MEDIUM DUTY VEHICLES

Fuel penalty information for the various control systems considered is summarized in Table 2.15. Indicated in the table are the sources of the data used to estimate the fuel penalty for each system. Typical data are given in Appendix A6. As in the case of emissions reduction factors R, it is assumed that the fuel penalty factor FP determined using LDV data is also applicable for trucks independent of inertia weight.

2.6.2.3 Effect of Emissions Control on Truck Driveability and Engine Selection

In addition to the fuel penalty which was discussed in the previous section, the use of emissions control systems on conventional gasoline engines can lead to other undesireable side-effects on vehicle operation. These other side effects which are often grouped together and called driveability problems include surge and hestitation during acceleration, rough idle or stall when the engine is cold, and reduced vehicle performance (ex. rate of acceleration or maximum speed). The major source of these driveability problems is the control means taken to reduce the NO_x emissions. These include EGR, retarded timing, and very lean carbureter A/F ratios. The result is less efficient and rougher combustion especially at high engine RPM. These effects are shown in Figure 2.12 which was taken from Reference (21). Note that the average peak pressure is reduced by about 15% using 10% EGR and that the cycle-to-cycle torque variation increases significantly with both % EGR and leaner A/F ratios. Hence in order to maintain a desired engine smoothness and response it becomes necessary to operate at richer carbureter settings when EGR is used. This results in reduced fuel economy. Driveability problems associated with cold engine operation are less basic and are presently being minimized using quick heat air induction systems and programmed spark advance. It can be expected that driveability problems due to the use of EGR will decrease as more sophisticated carbureters are developed.

The effect of EGR and the other means of controlling NO_x emis-

Table 2. 15 Summary of Emission Control System Fuel Penalty Factors

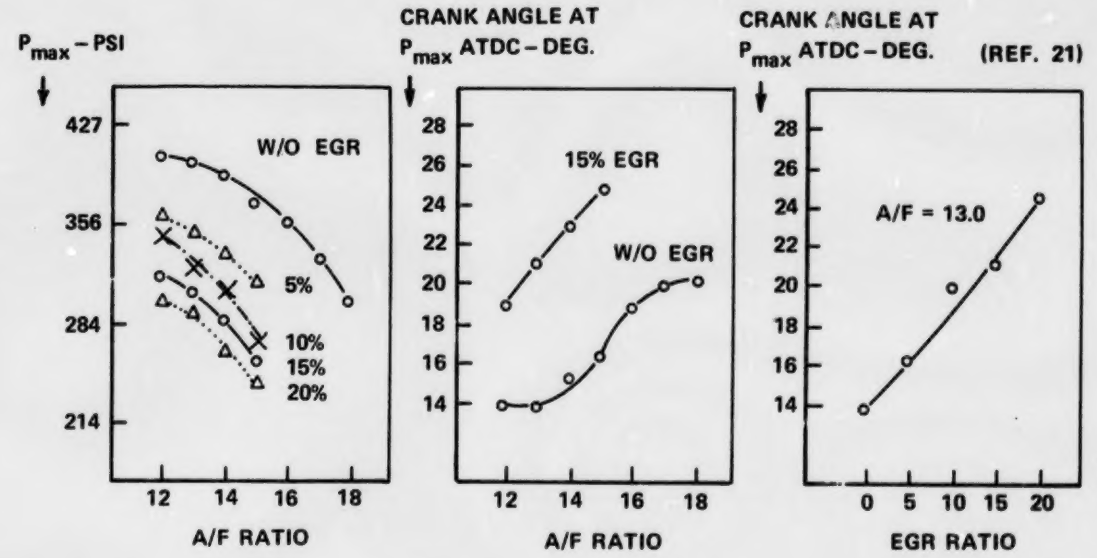
No.	System	Fuel Penalty Factor(2) (%)	Sources/Tables(3)
0	EM°(1)	-	-
1.	EM° + EI + FC + AI + EGR	7 ± 3	Reference (9)
2.	EM° + EI + IC + QHI + AI + EGR	5 ± 2	Reference (10, 11, 13)
3.	EM° + EI + IC + QHI + EGR + AI + OC	8 ± 2	Reference (10, 11), Table A6. 1
4.	EM° + EI + IC + EGR + RC + AI/CAI + OC	12 ± 2	Reference (2)
5.	EM° + EI + EFIC + EGR + RC/OC	3 ± 2	Reference (15)
6.	EM° + EI + IC + QHI + EGR + LTR	8 ± 2	Reference (16), Table A6. 2
7.	EM° + EI + FC + EGR + AI + RTR	25 ± 5	Reference (13), Table A5. 6
8.	EM° + EI + FIC + IQHI + AI + EGR	3 ± 2	Reference (10, 11)

(1) Baseline engine - 1972 (baseline fuel economy)

(2) Fuel penalty in urban driving (LA-4 driving cycle)

(3) Tables found in Appendixes A5, A6.

ENGINE SPEED: 2000 RPM - BRAKE MEAN EFFECTIVE PRESSURE: 42.7 PSI - IGNITION TIMING: 40° BTDC



ENGINE SPEED: 2000 RPM – TORQUE: 26 FT.-LB. - IGNITION TIMING: 40° BTDC

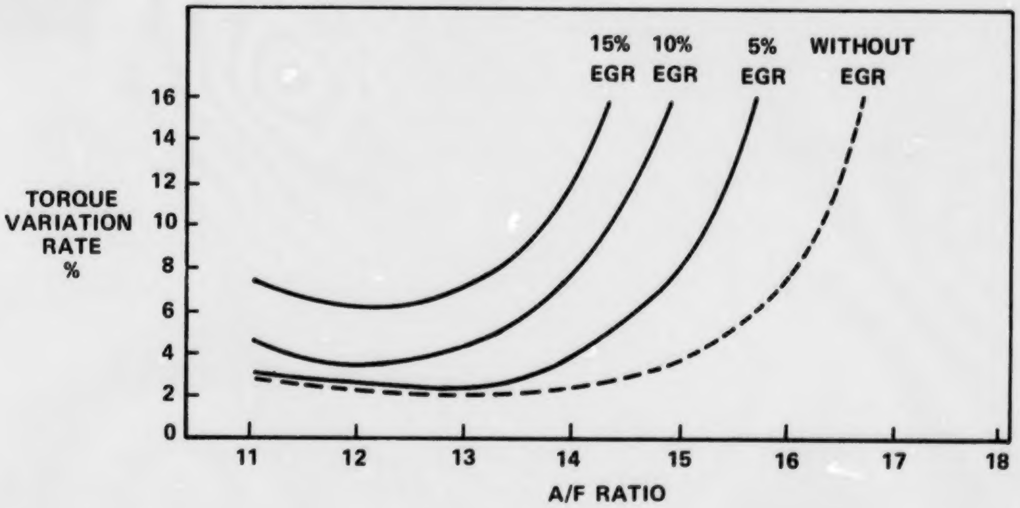


Figure 2.12 EFFECT OF EGR ON CYLINDER COMBUSTION PARAMETERS

sions on driveability will likely be more serious for trucks than LDV because the lower power-to-weight ratio of trucks and their driveline characteristics (gear and axle ratios) result in engine operation at high loads and engine RPM a greater fraction of the time. Hence a reduction in maximum horsepower and the occurrence of rough combustion at high RPM are more noticeable in MDV than in light duty vehicles. As a result it is likely that larger engines will be used in trucks than in the past and that it will be more difficult to attain the desired emissions reductions and at the same time maintain good vehicle driveability.

2.6.2.4 Emission Control System Characteristics (Data) for Medium Duty Trucks

As noted previously, the emission reduction and fuel penalty factors defined in the two previous sections were evaluated using light duty vehicle data. This was unavoidable because only very limited medium duty data were available. In this section, the available MDV data are summarized and their compatibility with the emissions reduction and fuel penalty factor predictions assessed.

Emission control system data pertinent to MDV with gasoline engines are available from two sources. EPA/Ann Arbor(18) tested two trucks which were retrofitted with EGR and an oxidizing catalyst; Southwest Research Institute (SWRI)(22) has performed a series of engine dynamometer tests on two V-8, heavy duty, gasoline engines fitted with various control systems including EGR, air injection, and an oxidizing catalyst. These two sets of data are summarized in Tables 2.16-17 for comparison with the previously determined emission reduction and fuel penalty factors.

In Table 2.16, composite emissions data for HC, CO, NO_x are shown for the pick-up truck and the stake truck tested at inertia weights between 5500 and 7000 lbs. Also shown are data for a light duty Ford F-100 truck having a 1975 prototype emissions control system tested at 4500 lbs.

TABLE 2.16

SUMMARY OF MEDIUM DUTY TRUCK EMISSION CONTROL SYSTEM EFFECTIVENESS DATA

Truck	Inertia Weight	Control System	Data Source	$HC^{(5)}$	R_{HC}	$CO^{(5)}$	R_{CO}	$NO_x^{(5)}$	R_{NO_x}	MPG	Fuel Penalty FP(%)
Pick-up(1972)	5500	none	EPA	3.23		44		6.43		11.2	
Pick-up(1972)	5500	EGR+OC(1)	EPA	.35	.108	3.29	.075	2.91	.454	10.25	9.0
Pick-up(1972)	6500	none	EPA	2.92		39.6		6.58		10.0	
Pick-up(1972)	6500	EGR+OC(1)	EPA	.50	.171	7.25	.181	4.02	.625	8.85	13.0
Stake(1972)	7000	none	EPA	7.99		81.9		7.49		10.2	
Stake(1972)	7000	EGR+OC(2)	EPA	1.20	.15	10.99	.134	4.16	.55	8.7	17
F-100(1975)(3)	4500	EGR+OC+AI	EPA	.20	.117(4)	1.39	.085	2.56	.63	10.8	10

(1) 60 in^3 volume, retrofit

(2) 180 in^3 volume, retrofit

(3) 1975 prototype Ford System

(4) Reduction factors calculated from baseline emissions (1972 LDV)

(5) All emissions in gm/mi using 1975 CVS-CH test procedure

TABLE 2.17

SUMMARY OF ENGINE DYNAMOMETER EMISSION CONTROL SYSTEM EFFECTIVENESS DATA

			Emissions (gm/bhp-hr)							
Engine	Source(1)	Control System	HC	R_{HC}	CO	R_{CO}	NO_x	R_{NO_x}	bsfc lb/hp-hr	Fuel Penalty FP(%)
V-8, 350 CID(2)	SWRI	none	8.82		31.4		10.85		.620	
V-8, 350 CID	SWRI	EGR+OC+AI	2.22	.25	18.6	.59	6.23	.58	.667	7.5
V-8, 361 CID(3)	SWRI	none	13.0		35.4		11.00		.733	
V-8, 361 CID	SWRI	EGR+OC+AI	1.31	.104	19.2	.54	4.09	.39	.831	11.2

(1) Data taken from Reference (22)

(2) 350 CID engine designated as 2-3 in Reference (22)

(3) 361 CID engine designated as 1-3 in Reference (22)

For each truck, the emission reduction and penalty factors are shown in the table. It is encouraging that in most instances the factors fall within the ranges given in Tables 2.14. It is also of interest to compare the composite emissions and bag data for the retrofitted trucks tested at EPA and the corresponding emissions data for the light duty truck equipped with the 1975 prototype control system. Such data are shown in Table 2.18. Note that in general the trends of the emissions from bag-to-bag are very similar for the retrofitted medium duty trucks and the "factory equipped" light duty truck indicating that the behavior of the catalyst in cold as compared to hot starts and hot transient operation is essentially unchanged over the weight range. This again offers encouragement that the reduction factors obtained from LDV data are applicable for medium duty vehicles. It also shows for MDV as for LDV the dominance of the engine warmup HC and CO emissions on the composite vehicle emissions for the 1975 CVS-CH test procedure.

The engine dynamometer emissions data from SWRI (22) are summarized in Table 2.17. The engines were tested using the 23-mode cycle with the composite cycle emissions given in terms of gm/bhp-hr. The effective emissions reduction factors for each pollutant were determined by dividing the controlled and uncontrolled composite cycle emissions values. The reduction factors for the HC and NO_x are in reasonable agreement with those given in Table 2.14, but the reduction in CO emissions is much smaller than would be expected with the use of a catalytic reactor.

Fuel penalty factor results are also shown in Tables 2.16-17. As in the case of the reduction factors, the fuel penalty results from the truck tests are in reasonable agreement with the values obtained from LDV data.

2.6.2.5 Differences Between Controlling Emissions from Light Duty and Medium Duty Vehicles

The preceding considerations of reducing emissions from medium

TABLE 2.18

BAG EMISSIONS DATA[(1)] FROM LIGHT DUTY AND MEDIUM DUTY VEHICLES

Vehicle	Inertia Weight	Control System	Composite Emissions (gm/mi)			Bag #1 Emission (gm/mi)			Bag #3			Bag #2		
			HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1973 Chev(2)	4500	System 1	2.75	24.1	2.7	3.6	30.0	3.25	2.9	27.6	3.07	2.65	22.3	1.96
1975 Chev	4500	System 3	.38	1.86	2.2	1.00	7.53	3.26	.38	1.93	2.49	.15	.09	1.66
1975 Plym	4500	System 3	.38	4.11	2.80	1.39	16.2	3.19	.15	1.80	3.0	.10	.57	2.54
1975 Buick	4500	System 3	.34	2.27	1.47	.87	9.08	2.08	.23	.90	1.47	.09	.30	1.23
1975 F-100	4500	System 3	.20	1.39	2.56	.35	7.47	2.82	.33	.65	3.02	.10	.16	2.21
1972 Stake truck	5500	EGR + OC(3)	.97	7.75	3.5	2.2	25.0	4.0	.66	5.4	4.6	.645	2.06	2.76
1972 Stake truck	6000	EGR + OC(3)	1.13	11.0	4.5	2.69	29.0	5.1	.85	8.6	5.8	.68	5.0	3.8
1972 Stake truck	6500	EGR + OC(3)	1.11	11.5	4.36	2.66	35.0	5.3	.72	8.84	6.25	.70	5.55	2.94
1972 Stake truck	7000	EGR + OC(3)	1.2	11.7	4.1	2.90	35.0	4.8	.80	9.1	5.2	.69	3.50	3.20
1972 Stake truck	7000	None	7.7	82.0	7.6	8.6	88.0	8.6	6.8	75.0	8.54	7.8	82.0	7.5
1972 Chev Pickup	5500	None	3.3	47.0	6.0	4.3	62.0	7.2	2.8	29.0	7.6	3.2	52.0	4.6
1972 Chev Pickup	5500	EGR + OC(4)	.34	2.9	2.9	.82	11.5	3.86	.25	1.2	3.72	.19	.38	2.09
1972 Chev Pickup	6500	EGR + OC(4)	.51	7.2	4.0	1.20	2.3	4.85	.46	-	-	.25	.76	2.67
1972 Chev Pickup	6500	None	3.0	41.0	6.7	6.7	5.7	7.87	3.0	3.3	8.5	2.9	39.	5.2

(1) Low mileage; Date received from EPA

(2) This data taken at Calspan

(3) Retrofit; OC Vol = 60 in^3

(4) Retrofit; OC Vol = 180 in^3

duty trucks have rested heavily on experience and data from control systems on light duty vehicles. There are, however, differences in controlling emissions from vehicles in the two weight classes which should be considered. These differences are mainly due to the fact that the power-to-weight ratio of light duty vehicles does not change significantly with weight. For medium duty trucks, however, the power-to-weight ratio tends to decrease as the GVW increases. This occurs for the most part because the same size (CID) engines are used in both standard-sized cars and medium duty trucks. When the engine is used in a MDV, it operates at a higher load which on the average results in higher emissions with increasing vehicle weight (see Figures 2.7-9). As shown by the pre-control surveillance data for LDV given in Reference (39), this is not the case for LDV except for NO_x emissions since the emissions levels found for HC and CO did not vary systematically with vehicle weight up to 5500 pounds. An analytical method for estimating the increase in baseline emissions with weight for MDV has been developed. The method is described in some detail in Appendix A7 with only the basic approach and numerical results being given in the main body of the report (Section 2.6.2.5.1). The effect of the increased engine load on the design and operation of the various control systems is then discussed qualitatively in Section 2.6.2.5.2.

2.6.2.5.1 Incremental Effect of Vehicle Weight on Baseline Emissions

As shown in Figures 2.7-9, the baseline emissions of MDV increase with vehicle inertia weight. This increase in emissions is usually attributed to the higher engine HP required to propel the heavier vehicle. A simple analytical method was developed to predict the effect of vehicle weight on emissions (gm/hr) as a function of load (HP) and engine RPM, vehicle characteristics (weight, frontal area, drag coefficient, rolling resistance, axle ratio, etc.), and driving cycle (average speed, percent time in acceleration and cruise, etc.). The method, which does not attempt to account for the effect of cold starts or driving transients, is described in Appendix A7. It is assumed that most of the incremental emissions beyond that for a standard size LDV with the same engine are due to the increased horsepower required to accelerate the vehicle and to maintain cruise velocity. Hence only the incremental and not the baseline LDV emissions are calculated.

Four vehicle classes are considered in the analysis - pick-up truck, van, stop-van, and passenger car. For each vehicle class, the mean horsepower required in acceleration and cruise driving modes is calculated from the following equation.

$$(\mathrm{HP})\ \mathrm{road} = \frac{1}{550} \quad .0668\ W\ V\ \frac{d\ V}{dt} \quad + \quad .0039\ C_D\ A_F\ \overline{V3}$$
$$+ \quad V\ W\ (K_1 + K_2\ V)$$

where

W = Vehicle weight (lbs)

C_D, A_F = Drag coeeficient and front area (ft^2) of the vehicle

V = Speed (mph)

$\frac{d\ V}{dt}$ = Acceleration (mph/sec)

$\overline{V^3}$ = Average of the velocity cubed

K_1, K_2 = Constants in the rolling resistance equation

The constants associated with each class of vehicles are given below.

Vehicle	C_D	A_F (ft^2)	K_1	K_2
Pick-up Truck	.5	29	.015	.00026
Van	.65	34	.015	.00026
Stop-Van	.65	44	.014	.00022
Passenger Car	.45	21	.017	.000334

In order to caluculate the mean horsepower in the acceleration and cruise modes appropriate to the LA-4 driving cycles, one requires values for the following quantities.

V = average velocity in the mode

$\frac{d\ V}{dt}$ = average acceleration in the mode

$\overline{V^3}$ = average of the velocity cubed in the mode

Such information is conveniently summarized in ref (23). In the present work, the 5-city composite results were used as they compare closest with the LA-4 cycle. Distribution of total time in mode, acceleration, and velocity mode data are given in Appendix A7. The driving cycle inputs needed to calculate the mean horsepower and incremental emissions are summarized in Table 2.19.

Eq. (1) was evaluated for the four vehicle classes and a range of vehicle weight. The results are shown in Table 2.20. As expected the required mean horsepower for both acceleration and cruise modes increases with vehicle weight. The engine RPM for the two operating modes of interest were also determined. It was found that

		Eng. RPM	
Mode	Velocity	Car	Truck
Acceleration	26	1450	1970
Cruise	37	1300	1770

Now one can proceed to calculate the incremental emissions from the engine emission mapping data.

It was assumed that all the vehicles were powered by a V-8, 350 CID engine. Engine dynamometer emissions data for that engine are given in Reference (22) (designated as 2-3 in that report). Unfortunately, the test cycle included only 1200 and 2300 RPM as shown in Figures A-7.2-4. Intermediate RPM were faired in following the general shape of two bounding data curves. The general approach taken was to calculate the difference between the emissions from a truck of weight I_w and a reference passenger car of weight 4500 having the same engine. The average emissions from the reference passenger car for the LA-4 driving cycle are well know from emissions tests. It is assumed that the trucks are tested on the same LA-4 driving cycle. Hence the total cycle time is 23 minutes and the length of the route is 7.5 miles. Now the incremental emissions from a truck can be written as

TABLE 2.19

URBAN DRIVING CYCLE CHARACTERIZATION DATA(1)

Mode	Total Time in Mode % 5-City Composite	N.Y.C.	LA-4
Idle	12.9	17.5	13.6
Cruise	31.8	26.5	27.3
Acceleration	29.1	29.1	31.7
Deceleration	26.2	27.0	27.5

Mode(2)	Average Velocity V_1 (mph)	Average Acceleration dv/dt (mph/sec)	$\overline{V}^3$
Acceleration	26	.8	25,000
Cruise	37	0	76,700

(1) Data obtained from Ref (23)

(2) Average conditions are for the 5-city composite

TABLE 2.20

ROAD AND ENGINE HORSEPOWERS FOR ACCELERATION AND CRUISE MODES

	Acceleration Mode			Cruise Mode		
		HP			HP	
W	Pick-Up	Van	Stop-Van	Pick-Up	Van	Stop-Van
4500	18.6	19.9	20.6	15.3	19.5	22.3
	(24.8)	(26.5)	(27.2)	(16.9)	(21.6)	(24.8)
6000	23.9	25.2	25.8	17.8	22	24.5
	(31.9)	(33.4)	(34.2)	(19.8)	(24.4)	(27.3)
8000	31.0	32.4	32.7	21.1	25.3	27.5
	(41.2)	(43.0)	(43.4)	(23.4)	(26.0)	(30.5)
10000	38.1	39.5	39.7	24.5	28.6	30.4
	(50.5)	(52.5)	(52.7)	(27.2)	(31.7)	(33.6)
12000	45.2	46.6	46.6	27.8	31.9	33.4
	(60.2)	(61.8)	(61.8)	(30.8)	(34.4)	(37.2)
	52.3	53.7	53.5	31.0	35.2	36.4
	(69.5)	(71.5)	(71)	(34.4)	(39.2)	(40.5)

Top number ≡ road horsepower

Bottom number ≡ engine horsepower

Values for 4500 passenger car

Acceleration Mode	Cruise Mode
18.5	14.0
(24.7)	(15.5)

$$\Delta E \text{ (gm/mi)} = \left[\left(\frac{\text{gm E}}{\text{hr}}\right)_{\text{truck}} - \left(\frac{\text{gm E}}{\text{hr}}\right)_{\substack{4500\\ \text{car}}} \right] \frac{\frac{23}{60}\,(\%\text{ time in mode})}{7.5\text{ mi}}$$

$$E = HC,\ CO,\ NO_x \qquad (2)$$

Equation (2) is applied for both the acceleration and the cruise mode. GmE/hr are obtained from Figures A-7.2-4 using the appropriate values of HP and engine RPM. Table A-7.2 shows a typical set of calculations for the van-truck.

The computed emissions results are compared with the medium duty truck baseline correlations as a function of inertia weight in Figure 2.13. In the case of HC and NO_x the prediction procedure does reasonably well in accounting for the effect of vehicle weight and in giving a reasonable estimate of the initial value at I = 4500 lbs. In the case of CO, however, both the trend with weight and the initial value are much less than was found experimentally. These large discrepancies are probably due to the importance of the cold start and the fact that the mean horsepower approach does not account for time spent near rated horsepower where the specific emissions (gm/bhp-hr) are very high. As might be expected the averaging approach works best for NO_x emissions which vary smoothly with HP.

2.6.2.5.2 Differences in the design and operation of Emissions Control Systems in Trucks and Cars.

As noted previously a key assumption in the present study was that the same emission reduction effectiveness could be achieved with a given control system in a medium duty truck as in a light duty vehicle. In addition, satisfactory system durability and vehicle driveability are required in the truck. There are, however, several reasons why it might prove to be difficult to attain these goals for certain truck/engine/control system combinations. These differences between the design and operation of emissions control systems in medium duty trucks and passenger cars are considered in this section.

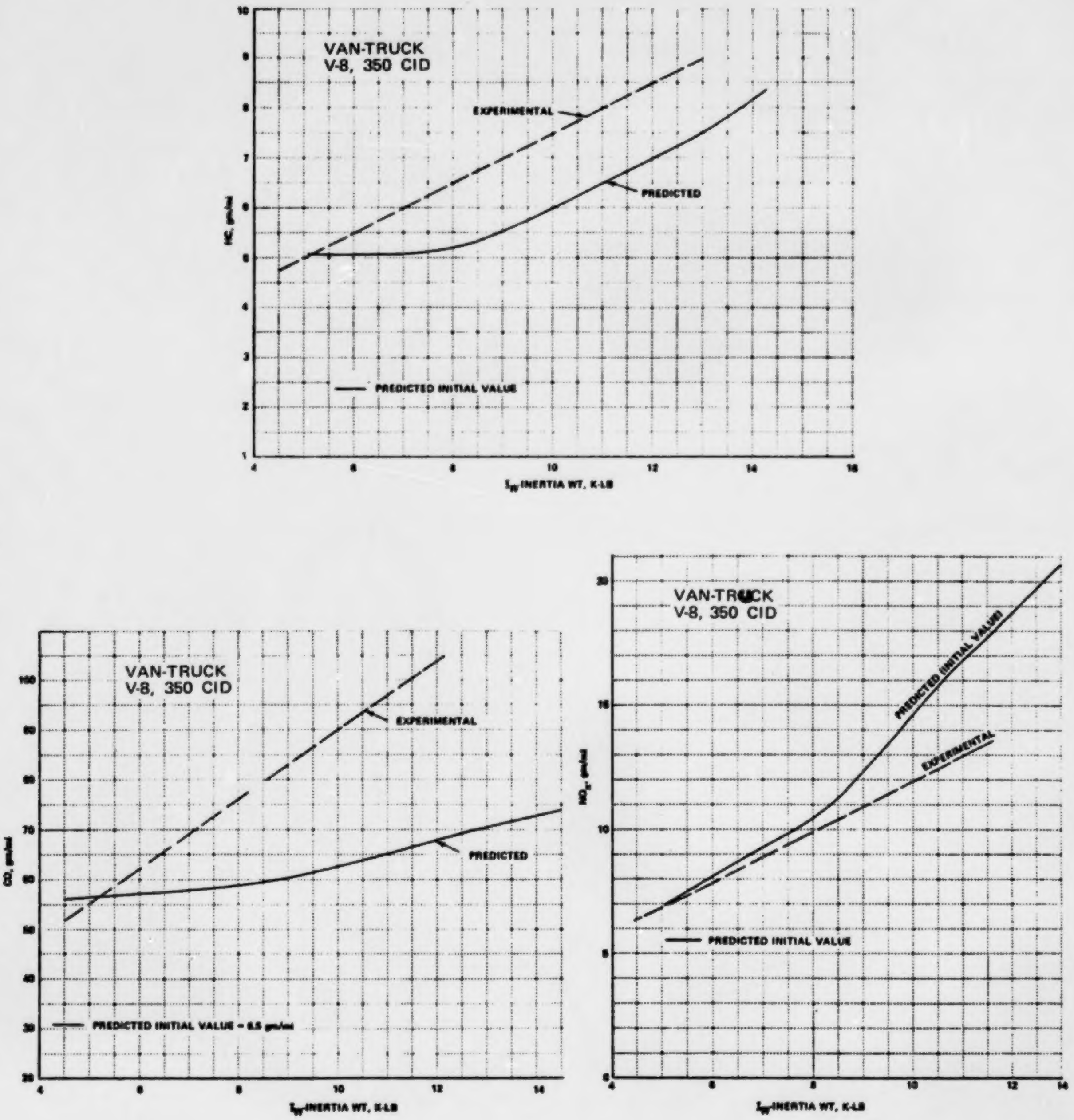


Figure 2.13 COMPARISON OF PREDICTED AND MEASURED EMISSIONS AS A FUNCTION OF VEHICLE INERTIA WEIGHT

As discussed in the previous section, it is common practice for many MDV to operate at much lower power-to-weight ratios than for passenger cars. Hence when used in a truck an engine operates at a greater fraction of its rated horsepower than in a car. The increase in engine load (HP) was calculated as a function of vehicle weight and shape in the previous section. In addition, at a given vehicle speed, the engine RPM is higher for a truck than a passenger car because the axle ratio used in trucks is considerably higher. The higher axle ratio is needed to partially compensate for the lower power-to-weight ratio. Hence, in general, a given engine operates at a higher load (HP) and higher speed (RPM) when it is used in a truck than in a car. These differences in engine operating conditions can have important consequences in applying the various control systems to medium duty trucks.

Consider first the effect of higher engine RPM. This could make it more difficult to maintain acceptable driveability when using EGR, retarded spark timing, and lean carburetor settings to reduce NO_x and lead to the use of larger engines (greater CID) in medium duty trucks than is the current practice. Acceptable driveability could also be maintained by using richer carburetion but this would result in an additional fuel penalty. Both of these approaches to solving the driveability problem would lead to higher operating costs. Improved fuel systems (carbureters, fuel injection, etc.) and more sophisticated control of proportional EGR systems hopefully will minimize driveability problem in trucks with reduced NO_x emissions and not require either of the above remedies.

Engines in trucks also operate at higher horsepower than those in cars for a given type of driving. This can have important consequences relative to the durability of catalytic converters, because it results in higher pollutant flow rates and exhaust gas temperatures than would be experienced in a light duty vehicle. The higher heat load to the catalytic converter would occur both during part-to-full throttle and motoring (deceleration) modes of engine operation. It is likely that the higher catalyst operating temperature will at least compensate for the reduced gas residence time and, as a result, the conversion efficiency of the converter in the MDV will be at least as high as in a LDV. However, it can be expected that to attain the required system durability and to optimize the conversion efficiency (achieve minimum emissions) considerable development work(24) beyond that done for LDV will be necessary. In that work, various combinations of converter volume, location, catalyst loading, and cross-sectional flow area would be tested. In addition, more elaborate catalyst protection schemes than those found necessary for LDV will probably be needed for MDV because in the latter case the catalysts will operate at a higher average temperature.

2.6.3 Alternative Engines

The exhaust emissions from medium duty trucks can be reduced by replacing the conventional gasoline engine by an alternative engine having lower baseline emissions. As indicated in Table 2.12, a number of such power plants are being developed which can be considered for future use in MDV. At the present time, none of these alternative engines is developed to the point that mass production is possible within the next several year even though several of them are attractive possibilities to at least share the MDV engine market with the conventional gasoline engine within ten years. The most promising of the alternative engines are the light weight diesel and the three-valve carbureted pre-chamber (CVCC) engine. Development work on both of these engines is proceeding rapidly at the present time and it appears likely they could be in limited production in 5 or 6 years. The emissions and fuel consumption characteristics of these engines are discussed in the following sections.

2.6.3.1 Diesel Engines

At the present time diesel engines are used in the majority of heavy trucks (GVW>20,000 lbs) because they have better durability, lower maintanence costs, and superior fuel economy than the conventional gasoline engine. Diesel engines are, however, significantly heavier, larger, and initially more costly than the comparable gasoline engine of the same horsepower. It is these latter disadvantages which have precluded the extensive use of the diesel engine in medium duty trucks at the present time. Work is presently underway, mostly in Europe and Japan, to develop a light weight diesel engine that would be suitable for both light duty and medium duty truck applications. The approach being taken is to tradeoff some of the extreme durability (up to 500,000 miles before overhaul) for reductions in weight, size, and inital cost. In all probability, the advanced light weight diesel would be turbo charged and be of the pre-chamber design. It would still be slightly (25%) heavier and larger than the comparable gasoline engine, but would have significantly lower baseline emissions and fuel consumption. It is assumed in the present study that the emission and fuel consumption characteristics of the light weight diesel will be comparable to those of the present heavy duty versions of the same type (example, turbocharged pre-chamber or naturally aspirated direct injection). Considerable data are available for the heavy duty diesel engines presently being used on heavy duty trucks.

2.6.3.1.1 Emissions and Fuel Consumption Characteristics of Diesel Engines

Most of the emissions data pertinent to diesel enignes have been obtained on the engine dynamometer because for heavy duty vehicles, the emissions standards are set for the engine alone rather than for the vehicle/engine combination as in the case of light duty vehicles. The only chassis dynamometer (LA-4) emissions data (gm/mi) available for a vehicle using a diesel engine is that given in Reference (25) for the Mercedes 220 D which uses a 4-cylinder, naturally aspirated, pre-chamber engine. As expected the emissions levels for that vehicle with the diesel engine were much lower than the corresponding emissions for the vehicle with a gasoline engine, but no direct use was made of those data in the present program because of the size and type of the diesel engine used. Hence in the present work engine dynamometer emissions data are used and a method developed to convert them to driving cycle emissions (gm/mi) for a truck of specified weight and shape.

Engine dynamometer emissions data for diesels of various types are summarized in References (26, 27). The engines were tested using several test cycles (7, 9, 13, 23 - mode test procedures). All the data used herein were obtained using either the 13 or 23 - mode test procedures which were found in Reference (28) to yield equivalent results. The composite cycle emissions data are reported (26, 27) as gm/bhp-hr while the specific mass emissions for each steady-state mode are given as gm/hr for specified load (HP) and engine RPM. Composite cycle emissions data for uncontrolled diesel and gasoline engines are summarized in Table 2.21 using results reported in References (22, 26-28). Average baseline values for the HC, CO, NO_x emissions from a conventional gasoline engine, a turbocharged direct injection diesel and a turbocharged pre-chamber diesel are given at the bottom of Table 2.21 in terms of gm/bhp-hr. It is clear that the baseline HC and CO emissions for the diesel engines are much lower than for the gasoline engine. It is also of interest to note that the baseline NO_x emissions from the pre-chamber diesel are also significantly lower than for the gasoline engine.

In order to compare the diesel emissions with those previously estimated for the gasoline engine with and without emission controls, it is necessary to convert engine dynamometer emissions results (gm/bhp-hr) to driving cycle results (gm/mi). This can be done in an approximate manner by defining an average horsepower $\overline{HP}$ and average velocity $\overline{V}$ for the driving cycle. Then one can write;

$$\text{Emissions (gm/mi)} = \text{(C.F.) Emissions (gm/bhp-hr)}$$

where

$$\text{C.F.} = \overline{HP}/\overline{V}$$

TABLE 2.21

ENGINE EMISSIONS CHARACTERISTICS(1)

Engine	Source	Emissions - gm/bhp-hr			Fuel Consumption lb/bhp-hr
		HC	CO	NO_x	
gasoline-22(2)	B/M(28)	7.67	33.4	9.6	.649
gasoline-23	B/M(28)	8.30	41.6	9.6	.575
gasoline-2-3	SWRI(22)	8.73	29.6	10.3	.631
gasoline-1-3	SWRI(22)	13.34	32.3	11.7	.733
Diesel-16* p	B/M(28)	.28	1.11	4.8	.432
Diesel-18*	B/M(28)	2.34	3.74	12.6	.421
Diesel-19	B/M(28)	3.26	5.21	7.7	.502
Diesel-A	B/M(26)	1.9	10.0	8.7	-
Diesel-B	B/M(26)	3.1	4.2	6.7	-
Diesel-G*	B/M(26)	3.1	3.9	17.8	-
Diesel-H*	B/M(26)	2.6	4.9	11.7	-
Diesel-I* p	B/M(26)	.3	2.3	6.1	-
		Average Values			
gasoline		8	37.5	9.6	.647
Diesel-DI*		2.68	4.11	13.8	.421
Diesel-IDI* p		.29	1.71	5.5	.432

(1)	13/23 - mode test procedure
(2)	engine designation in source reference
*	turbocharged
p	pre-chamber
B/M	Bureau of Mines; SWRI - Southwest Research Institute
( )	reference

can be used as the conversion factor between the two sets of emissions data. The average horsepower can be calculated using the engine load results of Appendix A-7 and the driving mode data of Table 2.19 in the relation:

$$\overline{HP} = .318\ (\overline{HP})\ \text{cruise} + .291\ (\overline{HP})\ \text{acceleration}$$

The balance (≈40%) of the driving time is spent in idle and deceleration modes which are assumed to be accounted for in the original averaging of the 13-mode engine cycle data. $\overline{V}$ was taken to be 26 mph. The conversion factor C.F. calculated as a function of vehicle inertia weight for pick-up trucks and stop-vans is shown in Figure 2.14. Using C.F. and the average engine emissions data at the bottom of Table 2.21, driving cycle emissions (gm/mi) for HC, CO, NO_x were calculated and the results are shown in Figures 2.15-17 for medium duty trucks. Figures 2.15-17 show both the effect of weight on emissions and the large reduction in baseline HC and CO emissions which could be achieved by replacing the conventional gasoline engine with the turbocharged, pre-chamber diesel. The absolute magnitude of the predicted gasoline engine emissions are in reasonable, but certainly not exact, agreement with the experimental results for MDV given in Figures 2.7-9. Hence in estimating baseline emissions,results of Figures 2.7-9 are ratioed by the appropriate factor obtained by dividing the predicted emissions for the different engines types given in Figures 2.15-17. Estimated baseline emissions for diesel engine-powered MDV are given in Figure 2.18.

The baseline CO and HC emissions for the turbocharged, pre-chamber diesel are sufficiently low that is is reasonable to assert that it will not be necessary to reduce them further. Hence the only emission control considered for the diesel was a further reduction of NO_x. As shown by the data given in Table 2.22, NO_x emissions can be reduced in the diesel engine using EGR just as they can in the gasoline engine. Note also that the fuel penalty for using EGR in the diesel engine is smaller than in the gasoline engine. For

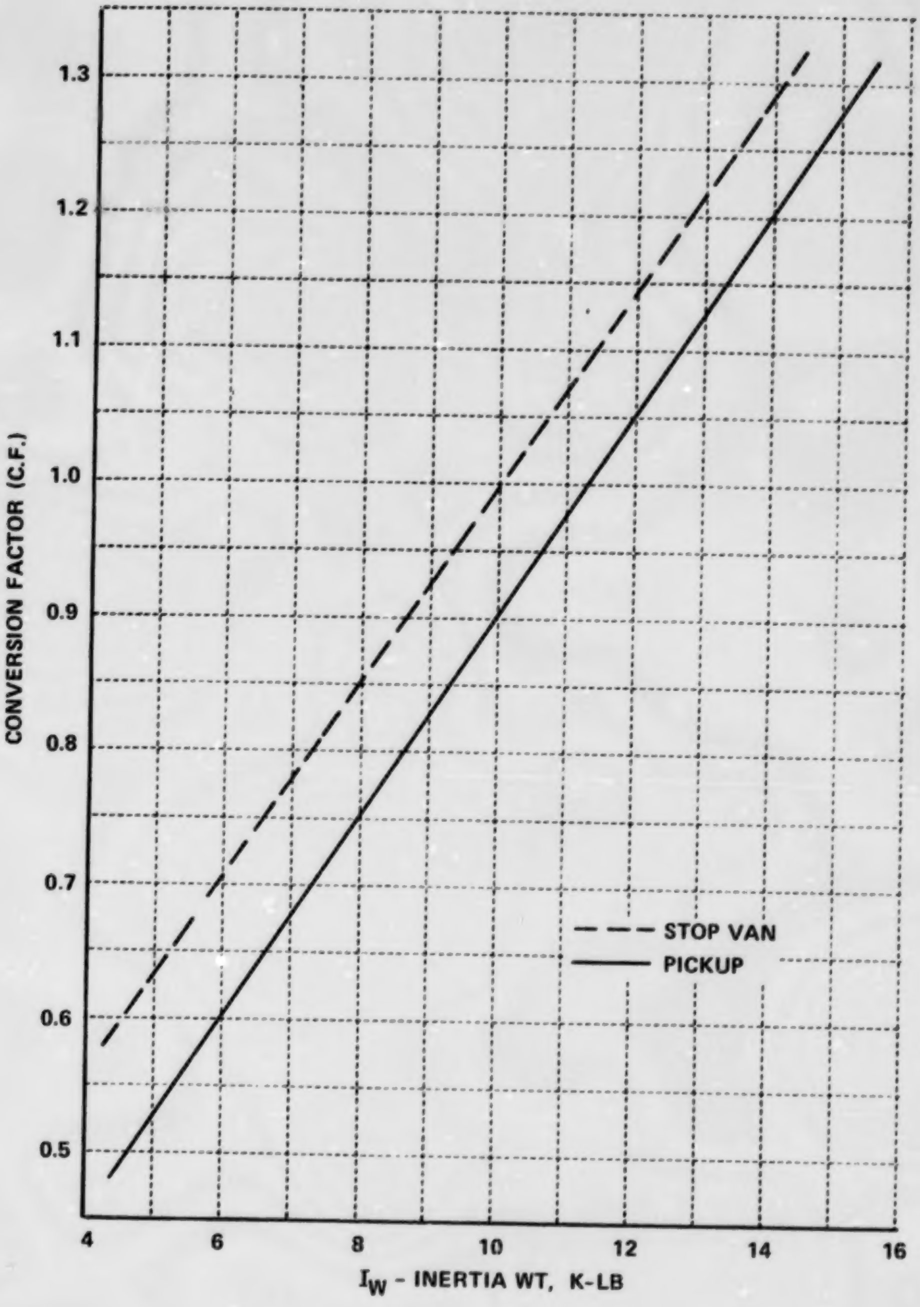


Figure 2.14 CONVERSION FACTOR BETWEEN ENGINE AND VEHICLE EMISSIONS

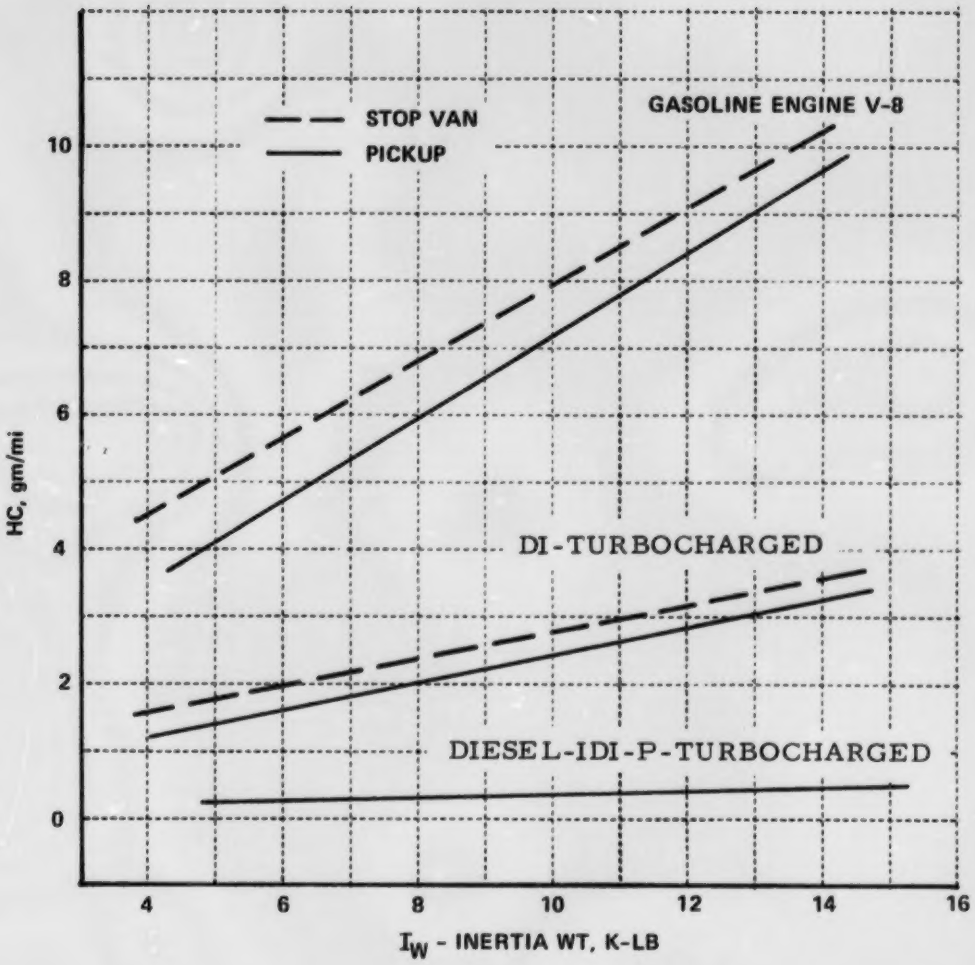


Figure 2.15 COMPARISON OF DIESEL AND GASOLINE ENGINE HC EMISSIONS FOR MEDIUM DUTY TRUCKS

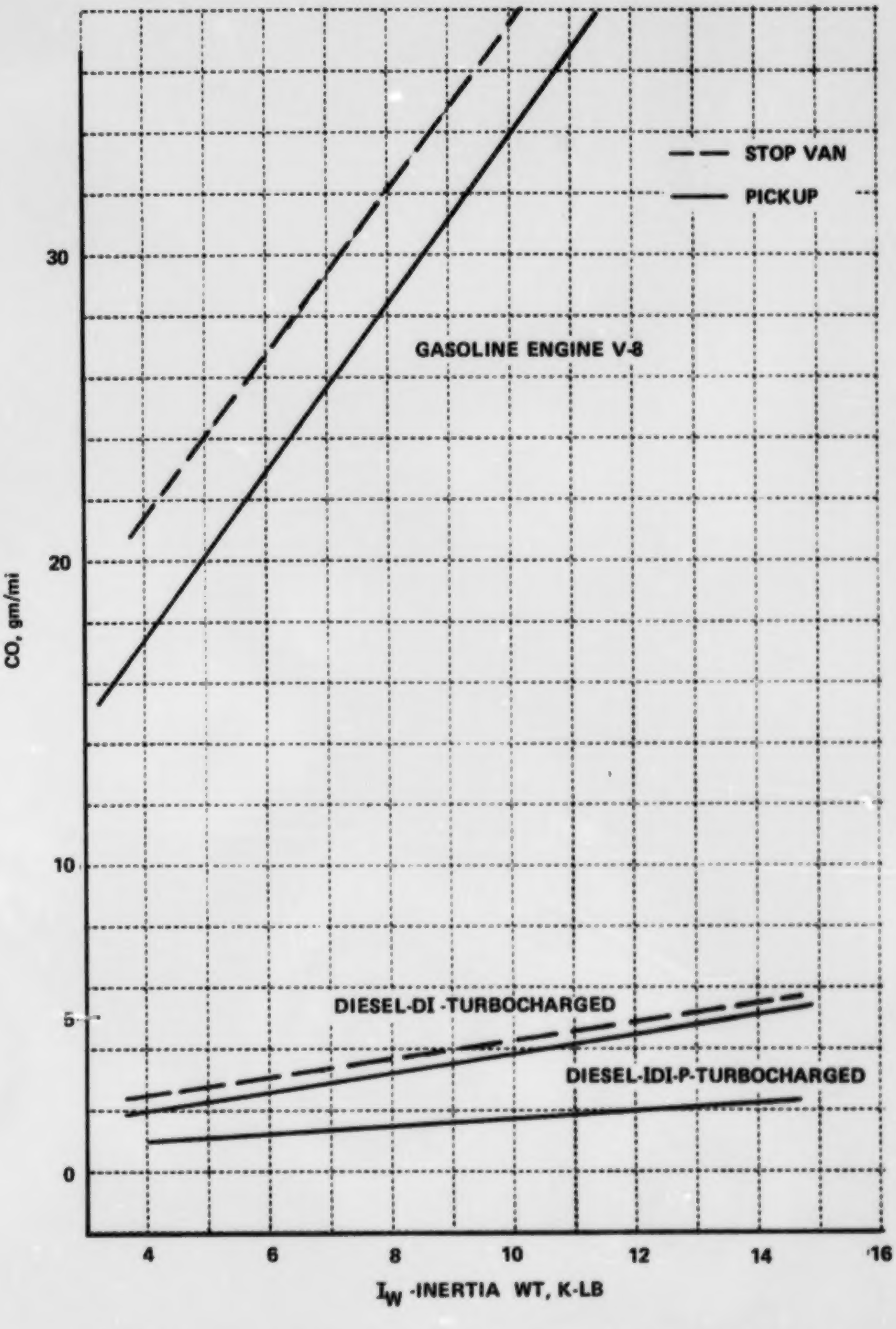


Figure 2.16 COMPARISON OF DIESEL AND GASOLINE CO EMISSIONS FOR MEDIUM DUTY TRUCKS

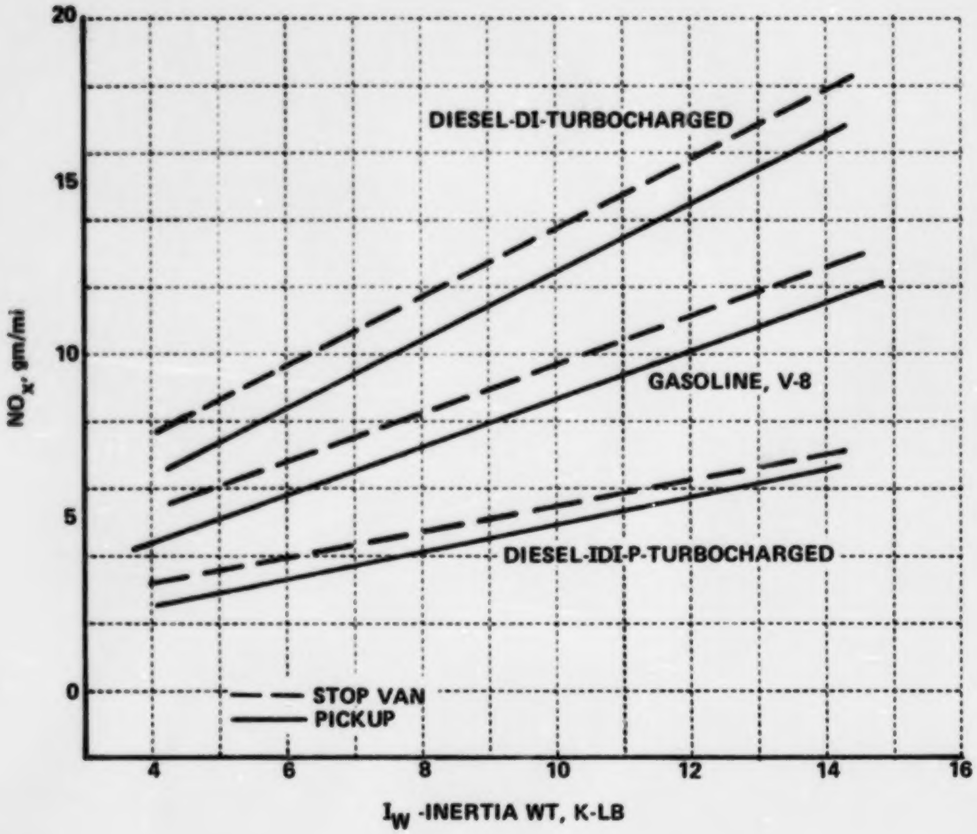


Figure 2.17 COMPARISON OF DIESEL AND GASOLINE ENGINE NO_x EMISSIONS FOR MEDIUM DUTY TRUCKS

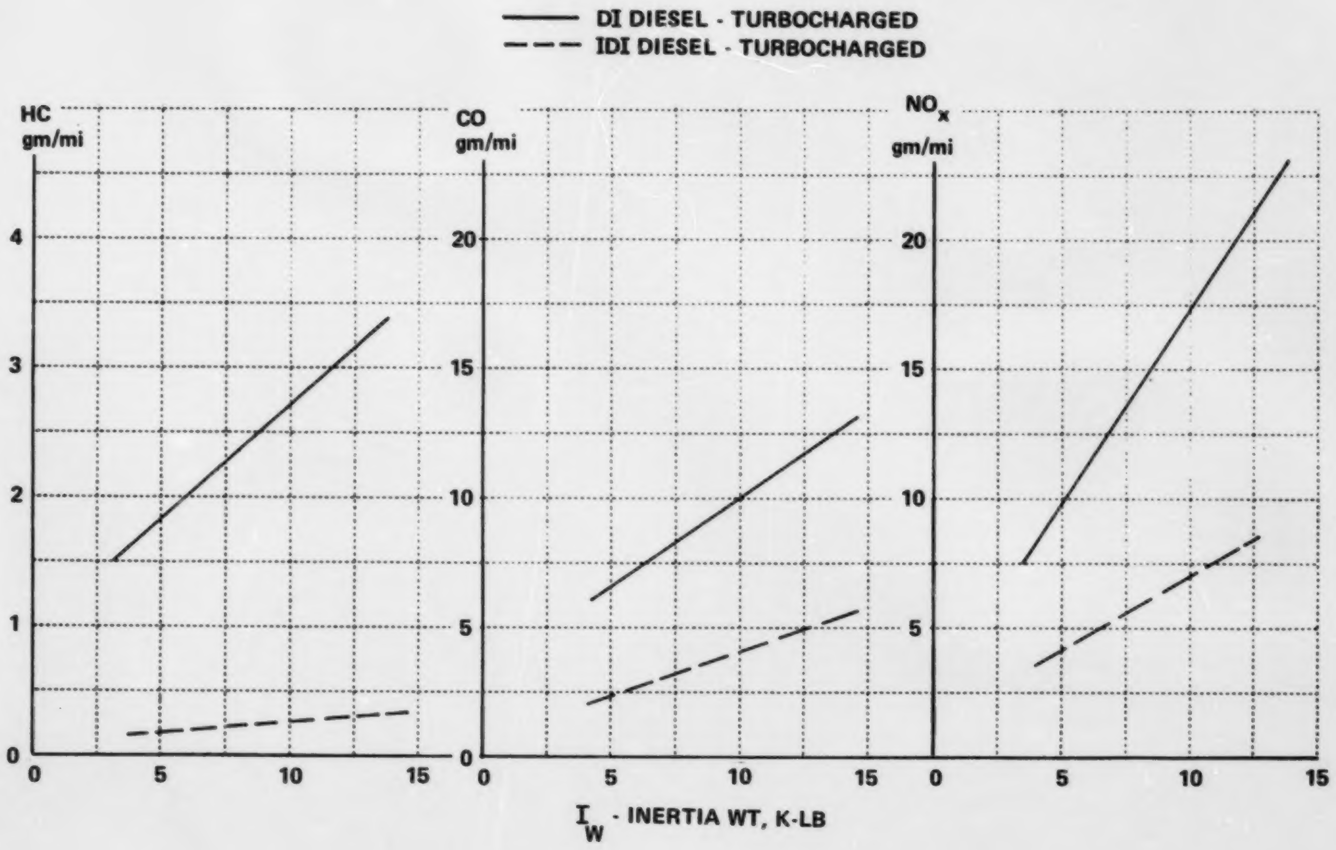


Figure 2.18 BASELINE DIESEL EMISSIONS (gm/mi)

TABLE 2.22

SUMMARY OF EMISSIONS FROM DIESEL ENGINES EQUIPPED WITH NO_x CONTROL SYSTEMS(1)

Emissions Data (2)

Engine	Control System	gm/bhp-hr HC	gm/bhp-hr CO	gm/bhp-hr NO_x	Peak Smoke (%)	lb/bhp-hr bsfc
IDI-P-turboch	none	.26	1.09	4.93	6.9	.422
IDI-P-turboch	5° injection adv, 10% EGR	.29	1.58	2.78	10	.443
IDI-P-turboch	5° injection adv, 10% EGR, inter cooling	.64	1.68	2.44	6.5	.430
DI	none	4.41	5.93	7.41	12.5	.504
DI	10% EGR	4.12	5.68	5.95	10.1	.510
DI	15% EGR	3.79	6.05	5.30	10.1	.520

Emission Reduction and Fuel Penalty Factors

Engine	Control System	Reduction Factors (R) HC	Reduction Factors (R) CO	Reduction Factors (R) NO_x	(FP) Fuel Penalty Factor
IDI-P-turboch	10% EGR	1.1	1.45	.562	1.04
	10% EGR, intercooling	2.4	1.54	.495	1.02
DI	10% EGR	.93	.96	.80	1.01

(1) Data from Ref (27)

(2) 13/23 - mode test procedure

a turbocharged, pre-chamber diesel, the appropriate emission reduction and fuel penalty factors are:

$$R_{NO_x} = .57 , \quad FP = 4\%$$

Fuel consumption data (bsfc) for the gasoline and diesel engines are also given in Table 2.21. Note that the fuel consumption of the diesel engine is significantly less (about 35%) than that for the gasoline engine. Hence, the estimated baseline fuel consumption of the diesel engine is given by:

$$(\overset{\circ}{Fe})_{diesel} = \frac{(bsfc)\ diesel}{(bsfc)\ gasoline} \quad (\overset{\circ}{Fe})_{gasoline}$$

$(\overset{\circ}{Fe})$ gasoline was given previously as a function of vehicle weight in Figure 2.11.

2.6.3.1.2 Odor and Particulate Emissions from Diesel Engines

In discussing the exhaust emissions from diesel engines, it is necessary to consider the odor and particulate (smoke) emissions in addition to the gaseous HC, CO, NO_x emissions. It is clear from the previous section that as far as the gaseous emissions are concerned, the diesel engine is an attractive power plant. Unfortunately part of this attractiveness is reduced by possible difficulties associated with odor and particulate emissions which are peculiar to the diesel. Less information is available concerning these latter diesel pollutants than for HC, CO, NO_x. The smoke and odor pollutants are easily perceived by the public even at quite low concentrations, so their control is critical for public acceptance of diesels for light and medium duty truck applications. It was concluded from the SWRI emissions tests(25) of the Mercedes 220 D that the odor and smoke emissions of that vehicle were objectionable and needed to be reduced.

Reducing the odor of the exhaust gases from the diesel is not a simple problem as it is even difficult to identify, let alone measure the concentration of, the odor causing species. This problem is discussed in some detail in Reference (29). There seems to be little assurance from the information in the literature that a solution to the diesel odor problem is close as its origin is not even well understood.

Reducing the particulate (smoke) emissions from the diesel engine is fortunately more straight forward than that of reducing odor emissions. In the case of particulate emissions, the concentration of the pollutant is easily measured and expressed in quantitative terms (mgm/ft^3) and its origin in the combustion process is reasonably well understood. Smoke (carbon particles) results when more fuel than can be burnt is injected into the cylinders and, hence, becomes a problem only at lugging and high engine loads. Current federal smoke emission standards for heavy duty engines are expressed in terms of exhaust gas stream opacity for various engine operating modes. For extensive urban use of diesels, it would seem that a reasonable minimum smoke standard would be that the exhaust not be visible at any engine operating mode. Studies have been made(30) which indicate that this requires the particulate concentration be always less than 7 mgm/ft^3, which corresponds to a smoke meter reading of about 10% opacity. This is considerably more restrictive than the present standard of 15-20%, but available diesel emission data(27) indicate it can probably be met without great difficulty. It should be noted(31, 32) that the use of EGR and injection retarding to reduce NO_x emissions aggravates the smoke problem. It is also of interest to compare the particulate emission (gm/mi) of gasoline and diesel engines for the LA-4 driving cycle. Typical gasoline engine particulate emissions(10) are:

.05 gm/mi - non-leaded fuel
.20 gm/mi - leaded fuel

Using the conversion factor (C. F.) of about .5 to relate driving cycle and engine dynamometer emissions, the gasoline engine particulate emissions become

.1 gm/bhp-hr - non-leaded fuel
.4 gm/bhp-hr - leaded fuel

for the engine dynamometer tests. This compares with values of .2-.6 gm/bhp-hr given in Reference (27) for diesel engines. Hence on a total particulate emissions basis, diesel engines are comparable to gasoline engines using leaded fuels.

2.6.3.2 Three-Valve Carbureted Pre-Chamber (CVCC) Engines

A recent modification(33) by Honda to the spark ignition gasoline engine termed the CVCC (Compound Vortex Controlled Combustion) or three-valve carbureted pre-chamber (stratified charge) engine has proven to have much lower baseline emissions than the conventional gasoline engine. Emissions tests(34, 35) have been made on Honda modified vehicles using both 4-cylinder and 8-cylinder engines. As indicated in Table 2.23, all the vehicles tested satisfied the 1975 standards for HC and CO without exhaust treatment devices. The NO_x emissions from the CVCC-powered vehicles without EGR were quite low being between .7 and 1.5 gm/mi depending on engine CID. In addition, the fuel economy data indicate that there is little, if any, fuel penalty associated with the CVCC modification of the gasoline engine.

The CVCC engines tested were modified versions of standard (production type), passenger car engines with only the head, timing gear train, and fuel system modified to accept the pre-chamber arrangement for the initiation of combustion. Work thus far on the CVCC engine concept has shown no reason why it cannot be used on intermediate to large V-8 engines suitable for medium duty trucks. Initially(40) it was thought that the CVCC concept was only applicable to small engines but more recent work(35) on a 350 CID, V-8 engine indicates this is probably not the case. 50,000 mile durability tests have been made on 4-cylinder, CVCC engines, but as yet the 8-cylinder version has not been durability tested. It can be expected that design and development testing work to adapt the CVCC concept to large V-8 engines will be pushed rapidly in the next couple of years. If the outcome of those efforts continues to look promising, then it seems likely that the CVCC engine will become a major alternative power plant for medium duty vehicles.

TABLE 2.23

EMISSIONS DATA FOR VEHICLES USING CVCC ENGINES

	Engine(1)			1975 CVS-CH Emissions Average level (gm/mi)			
Source	Cylinders	CID	Vehicle Weight(lbs)	HC	CO	NO_x	MPG
Ref (34)	4	125	2000 (2)	.18	2.12	.89	22.1
Ref (34)	4	125	2000 (3)	.24	1.75	.65	21.3
Ref (34)	4	125	3000 (2)	.28	3.08	1.56	19.4
Ref (35)	8	350	4500 (2)	.22	2.95	1.22	11.0

(1) No EGR or exhaust gas treatment

(2) Low mileage

(3) 50,000 mile durability test

2.7 Emission Control Strategies

The preceding sections of this report have identified eight different emission control systems which are likely candidates for use in medium duty vehicles to reduce exhaust emissions. Estimates have been made of their effectiveness in emission reduction, effects on fuel economy and vehicle performance. In addition, the capabilities of two alternative engines to the conventional gasoline engine have been similarly evaluated. From this selection of possible control systems, a wide range of control strategies can be hypothesized by taking into account the lead times required to bring these systems into the production stage.

The problem can be reduced to tractable proportions by focussing on a few strategies which may be taken as representative of the range of choices that is possible. Considering only conventional gasoline engines, the eight applicable control systems reduce to three basic approaches: (1) the use of improved fuel control (carburetion or fuel injection), (2) the use of catalytic converters and (3) the use of thermal reactors. Another factor is the alternative engine which can be shown entering production at appropriate times and in differing quantities to achieve a mix of vehicles equipped with different types of engines.

To evaluate the impact of different control strategies, a computer program has been devised to evaluate the projected annual emissions from medium duty vehicles through 1990 assuming implementation of a number of selected control strategies. A description of the computer program is included in a subsequent section. Specific examples of several representative control strategies that were subjected to analysis on the computer are described below. Project constraints on time and funds limited the number of possibilities that could be investigated to a total of six.

2.7.1 Conventional Gasoline Engines

A listing of the add-on emission control systems and their associated reduction factors is given in Table 2.10. To provide a simple, inclusive method for ranking each system according to its control effectiveness, a mean overall reduction factor for each system has been computed. This mean factor, obtained by averaging the individual pollutant factors, is substantially the same regardless whether the HC + CO + NO_x or the HC + NO_x factors are averaged. The usefulness of these mean factors lies in correlating the control systems with lead time information to program a decreasing emissions schedule. A summary of the mean reduction factors, the year of system availability and the relative ranking in effectiveness of each control system is given below.

CONTROL SYSTEM REDUCTION FACTORS

		Mean Reduction Factor			
No.	Control System	HC+CO+NO_x	HC+NO_x	Control Rank	Year Available
0	EM^o	1.0	1.0	0	1972
1.	EM^o + EI + FC + AI + EGR	0.98	0.98	8	1975
2.	EM^o + EI + IC + QHI + AI + EGR	0.60	0.62	7	1975
3.	EM^o + EI + IC + QHI + EGR + AI + OC	0.31	0.39	4	1977

No.	Control System	Mean Reduction Factor		Control Rank	Year Available
		HC+CO+NO$_x$	HC+NO$_x$		
4.	EM^o + EI + IC + QHI + EGR + RC + AI/CAI + OC	0.14	0.14	2	1978
5.	EM^o + EI + EFIC + EGR + RC/OC	0.14	0.14	1	1979
6.	EM^o + EI + IC + QHI + EGR + LTR	0.41	0.44	6	1977
7.	EM^o + EI + FC + EGR + AI + RTR	0.20	0.13	3	1977
8.	EM^o + EI + FIC + IQHI + AI + EGR	0.35	0.38	5	1978

Fuel control systems are identified by numbers 2 and 8, catalytic systems by numbers 3, 4 and 5, and thermal reactors by numbers 6 and 7. In combining these systems into a time-sequenced control scheme, the practical, economic realities must be recognized. For example, it would not be conceivable to consider specifying the use of a thermal reactor for one model year of vehicles and then to schedule a changeover to a catalytic converter system for the following model year.

2.7.1.1 Catalytic Converter Approach

Tabular data in the preceding section show that catalytic converters are potentially the most effective devices in achieving the lowest possible emissions among the set of devices that have been analyzed. Consequently, the most stringent emissions reductions will be realized using the catalytic approach. The following schedule represents a realistic maximum emissions reduction strategy.*

Control System No.	Model Years in Effect
2	1975, 1976
3	1977, 1978
5	1979, onward

This implementation strategy is representative not only of the most stringent control schedule but also probably the most desirable in a practical sense. It represents an evolutionary implementation of a catalytic system that results in an ultimate system that not only is highly effective in reducing emissions but accomplishes this at a very small cost in fuel economy. Thus other control strategies using catalytic devices were not considered useful.

2.7.1.2 Fuel Systems/Reactor Approach

As indicated by the heading of this section, the use of improved fuel control systems and thermal reactors in an emission reduction implementation scheme is possible in combination or singly. Of the two reactor systems listed, the rich thermal reactor can be disregarded as a viable approach. While a high level of emission reduction has been predicted for the rich reactor, the fuel penalty inherent with this system is just too costly and unacceptable in view of recognized need to conserve the supply of fossil fuels.

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* Note that the "catalytic converter approach" utilizes a non-catalytic system (#2) as the first stage of the implementation scheme.

Two fuel control strategies were selected for computer evaluation:

STRATEGY I

Control System No.	Model Years in Effect
2	1975 onward

STRATEGY II

Control System No.	Model Years in Effect
2	1975 - 1977
8	1978 onward

Strategy I represents a minimum approach to control with an average emission reduction of approximately 40% in each of the three major pollutants from the 1972 baseline levels. Strategy II follows that of I through 1978 when advanced carburetion and quick-heat induction systems are introduced with additional reductions achieved in HC, CO and NO_x together with improved fuel economy.

Only one reasonable strategy appears to exist for a combined fuel control/reactor approach.

Control System No.	Model Years in Effect
2	1975, 1976
6	1977 onward

While system 6 does not represent an improvement in either emissions reduction or fuel economy relative to system 8, it is an available alternative that needs to be assessed on the basis of cost effectiveness.

2.7.2 Alternative Engines

The discussion of alternative engines in Section 2.6.3 has made clear that at this time the lightweight diesel engine is the only new engine that can be realistically projected for use in medium duty vehicles. For this application, the use of a turbocharged, pre-chamber type of a high-rpm diesel equipped with EGR is envisioned. Sufficient information exists on this type of engine, both in terms of its exhaust emissions performance and fuel economy as well as costs, to permit a meaningful evaluation of its potential role as a low emissions power plant for the medium duty vehicle.

The three-valve, stratified-charge engine concept appears to offer the possibility of converting the conventional gasoline engine into a low-polluting power plant without the use of add-on control systems. Emissions performance data on engines of a size (CID) required for medium duty vehicle applications exist on only one, makeshift engine. Data on engine durability, costs and other important factors just are not available upon which an analysis can be made currently.

Diesel engines are projected as being in limited quantity production by 1978 and full-scale production by 1980. Two computer runs were made using a mix of diesels and conventional gasoline engines equipped with (1) the most stringent control system based on the catalytic converter approach and (2) the fuel control system approach.

2.7.3 Computer Simulation of Medium Duty Emission Control Strategies

As discussed in the previous sections, there are various control strategies that could be used to reduce emissions from medium duty vehicle.

In order to quantitatively assess the costs and benefits of the various strategies over a period of years, it is necessary to calculate the total yearly HC, CO, NO_x emissions (tons/yr) from all the medium duty vehicles on the road as well as the dollar costs (initial, operating, maintenance) associated with the emissions reduction in a given year. In any particular year, the MDV on the road represent a mix of vehicle ages, weight and body shapes, engine types, and emission control systems. The calculation of the total emissions and costs each year using a specified control strategy is straight forward, but cumbersome, because of the large amount of input data required to describe the medium duty vehicles in operation. Hence a computer program (AMTEC)* was written to calculate the emissions and costs pertinent to various control strategies. A detailed description of the program along with a Fortran listing is given in Appendix A-8. In this section, only the general approach taken in making the calculations, the required input information, and the primary program output quantities are discussed. Results obtained using AMTEC are presented in the next section.

In developing the program, the medium duty vehicles were divided into categories or groups according to vehicle weight and use (ex. 6,000 - 10,000 lb. trucks, 10,000 - 14,000 lb. motor homes). The vehicles in each group were then characterized by model year, engine type, and emissions control system. For example, one might have a 1977 6,000 - 10,000 lb. truck with a diesel engine equipped with EGR. Next it was necessary to characterize each vehicle/engine/control system combination in terms of emissions, fuel consumption, and initial and operating costs. In the case of emissions, the uncontrolled emissions for each model year vehicle/engine combination were input along with the reduction factors for a series of emission control systems which might be used with the engines. The baseline fuel consumption of each vehicle/engine combination was also input along with the fuel penalty associated with each of the emission control systems. It was assumed that the baseline fuel economy depended only on the vehicle/engine combination and not the model year. The costs (initial, operating, and maintenance) were input according to engine type and control system. The costs were taken to be independent of model year and vehicle group depending only on engine type and control system. In addition to characterizing the vehicle/engine/control system combinations, it was necessary to characterize the vehicle operation such as the maintenance program, miles traveled per year, and scrapage rate. Vehicle operation was characterized for each vehicle group.

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* Analysis of Medium (duty) Truck Emissions (and) Costs

The number of vehicles of each category that are on the road in any given year depends on the sales in previous years and the scrappage rate. The sales for each year are described in terms of vehicle group, fraction of vehicles in each group having each engine type, and the control system used on each engine type. Vehicle sales data was used going back to 1950 and projected to 1990. A summary of the input information required for AMTEC is given in Table 2.24. Most of the information needed was generated during the present medium duty truck emissions study and thus is documented in this report. When information from other sources is used, the source is noted in Table 2.24.

The time period considered in the present study was 1970 - 1990. The primary AMTEC output quantities, which are listed below, are calculated for each year of that period.

TABLE 2.24

SUMMARY OF REQUIRED INPUT INFORMATION FOR THE AMTEC PROGRAM

	Input Information	Source
1.	Sales for each year for each vehicle group (1950 - 1990)	1950-1972, Reference (38) 1973-1990, P.R.[1] (Figures 3.5-10)
2.	Fraction of engine types for each year and vehicle group	1950-1972, Reference (38) 1973-1990, C.S.[2]
3.	Baseline fuel economy (MPG) for each vehicle group and engine type	P.R. (Figure 2.11)
4.	Miles traveled per year for each vehicle group and vehicle age	Reference (37)
5.	Baseline H.C., CO, NO_x emissions for each vehicle group and model year for each engine type	1950-1972, Reference (39)[3] 1973-1990, P.R. (Figure 2.7-9)
6.	Fraction of vehicles of a given age remaining on the road for each vehicle group.	Reference (36)

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(1) P.R. - Present report

(2) C.S. - Specified emission control strategies

(3) The same trend with model year of pre-controlled emissions was assumed for MDV as was found in Reference (39) for LDV.

Table 2.24 (cont'd.)

	Input Information	Source	
7.	Emission reduction factors for HC, CO, NO_x for each combination of engine type and control system	P.R.	(Tables 2.14, 2.22)
8.	Fraction of engines of each type equipped with a given control system in each model year	C.S.	
9.	Fuel penalty factors for each engine and control system combination	P.R.	(Tables 2.15, 2.22)
10.	Fuel factors relating baseline fuel economy of various alternative engines to the conventional gasoline engine	P.R.	(Table 2.22)
11.	Incremental cost (initial and maintenance) for each engine and control system combination	P.R.	(Tables 3.6-9)

(1) Total HC, CO, NO_x emissions (tons/year)

(2) Total gasoline and diesel fuel consumed (gal/year)

(3) Incremental fuel consumed due to the use of emission control systems and alternative engines (gal/year)

(4) Incremental costs due to the use of emission control systems and alternative engines (dollars/year)

As indicated in Appendix A-8, the contribution to the total emissions, fuel consumption, and costs of the vehicles in each vehicle group is determined for each year by summing the contributions of the vehicles in that group from all model years. Then the contributions of the different vehicle groups are added to obtain the total emissions, fuel consumption, and costs for the year of interest. AMTEC results for various control strategies are presented in the next section.

2.7.4 Results of Computer Study

This section will discuss only those results of the computer program study which involve emissions and fuel economy. A total of seven different runs (designated as Cases I through VII) was processed and the results obtained for these specific situations are summarized herein.

Table 2.25 contains a listing of the seven test cases together with the general emission control approach used, the control systems involved and the year of their introduction into production vehicles. Two types of runs were made; one type in which all vehicles used only conventional engines (Cases I-V) and the other, in which a specific mix of conventional and diesel engines was considered. Attention is called to the fact that the

TABLE 2.25

SUMMARY OF COMPUTER RUNS

A. Conventional Gasoline Engines Only*

Case No.	Control Approach	Control System No.***	Year
I	None (1972 reference)	None	1972
II	Fuel Control	2	1975
III	Fuel Control	2	1975
		8	1978
IV	Thermal Reactor	2	1975
		6	1977
V	Catalytic Converter	2	1975
		3	1977
		5	1979

B. Conventional Gasoline Engines and Diesels (w/EGR)**

VI	Fuel Control	2	1975
		8	1978
VII	Catalytic Converter	2	1975
		3	1977
		5	1979

* In all cases the conventional engine was a 350 CID V-8

** The Diesel was taken to be equivalent to the 350 CID V-8 (same CID, turbocharged, pre-chamber, w/EGR)

*** See Table 2.10 for description - these systems are used only on conventional engines conventional engine, in all cases, was assumed to be a 350 CID V-8. Also the diesel, in all cases, was assumed to be a lightweight, turbocharged, pre-chamber engine with a 350 in^3 displacement and equipped with EGR. An assumed schedule of the chronological sequence and the quantity of diesel engine introduction into the MDV population is outlined in the following table.

ASSUMED SCHEDULE OF INTRODUCTION OF DIESEL ENGINES FOR COMPUTER STUDY- PERCENTAGE OF TOTAL VEHICLE ANNUAL SALES

	Trucks-GVW, lbs.		Motor Homes-GVW, lbs.	
Year	6,000-10,000	10,000-14,000	6,000-10,000	10,000-14,000
1978	5	10	5	10
1979	10	20	10	20
1980	25	35	25	35
1981	25	50	50	65
1982	25	65	50	65
1990	25	65	50	65

The computer program has a built in capability to divide the MDV category of vehicles into four groups according to GVW range and truck/motor home type. The results presented in this report pertain to the composite results only and include the entire range of GVW from 6,000 to 14,000 lbs. for all MDV vehicles.

Annual emissions data for an MDV population using only conventional engines and subjected to the four emission control implementation strategies shown in Table 2.25 are graphically illustrated in Figure 2.19

through 2.21. A separate presentation is made for HC, CO and NO_x and on each plot a reference emission curve is shown corresponding to a situation where the emissions of all new vehicles are maintained at 1972 baseline levels. The upward curvature of the reference trace merely reflects the increasing number of vehicles on the road in accord with the projected sales. Emission curves corresponding to the different control strategies will tend to curve upward (sooner or later depending upon degree of emission reduction) for the same reason.

The graphical data show that the relative effectiveness (in order of rank) of the four emission control strategies remains the same for all three pollutants. Case II, fuel control (system No. 2), is least effective while Case V, catalytic conversion (systems No. 2, 3 and 5) is the most effective. The two intermediate levels of effectiveness are substantially equivalent and correspond to the lean thermal reactor approach (Case IV) and the improved fuel control approach (Case III).

Similar data are graphically shown in Figures 2.22 through 2.24 for the situation where a mix of conventional and diesel engines is used in the MDV category of vehicles. Note that only the two implementation control strategies found to be most effective in the previous computer runs are used here. These two are the catalytic converter approach (here designated as Case VII) and the improved fuel control approach (designated Case VI). These control strategies are applied only to the conventional engines. Diesel engines are assumed to be equipped only with an EGR system.

It is instructive to compare the HC, CO and NO_x emission plots for the two conditions corresponding to conventional engines only and

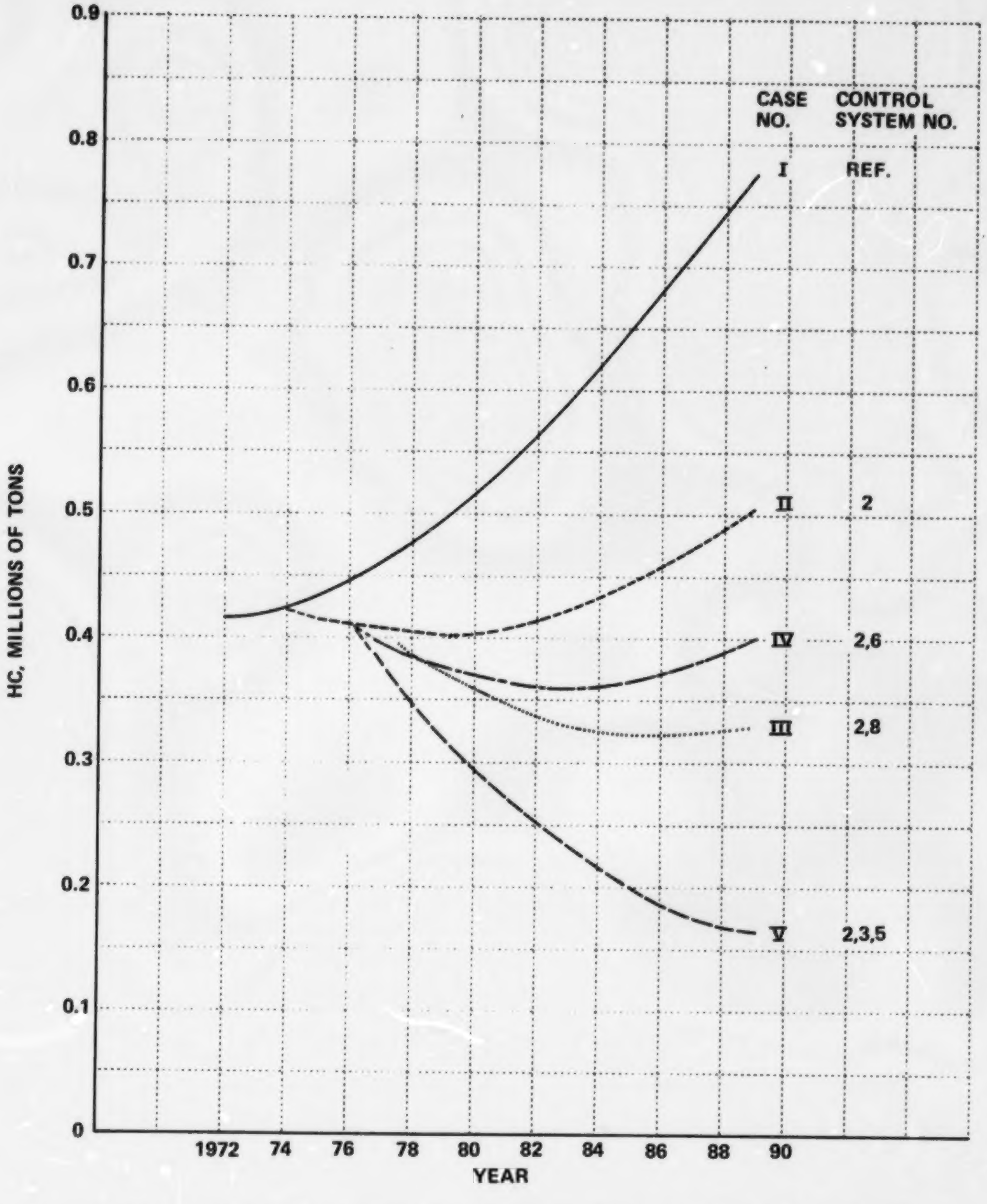

Figure 2.19 ANNUAL HC EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY -- CONVENTIONAL GASOLINE ENGINES ONLY -- MDV

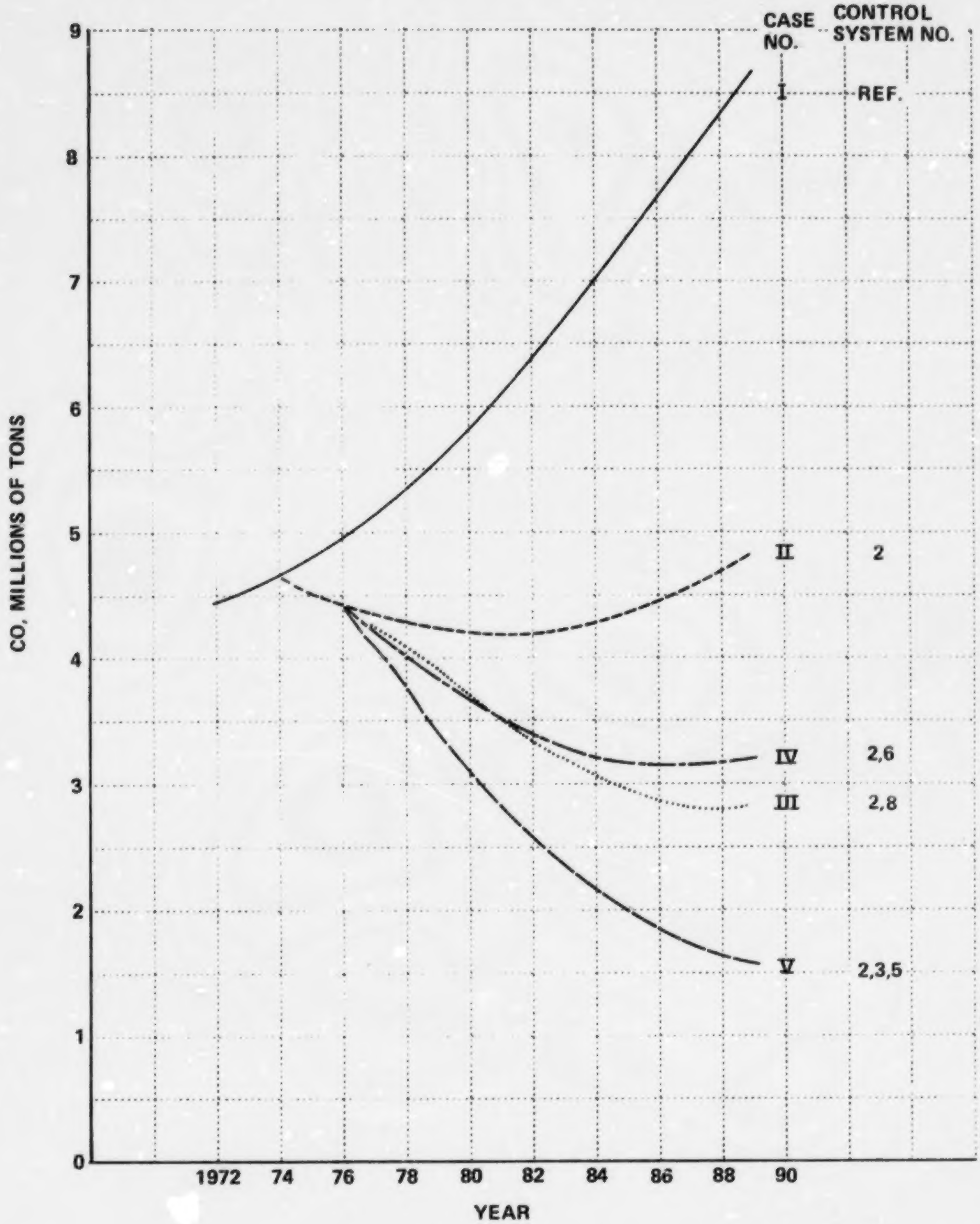

Figure 2.20 ANNUAL CO EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY -- CONVENTIONAL GASOLINE ENGINES ONLY -- MDV

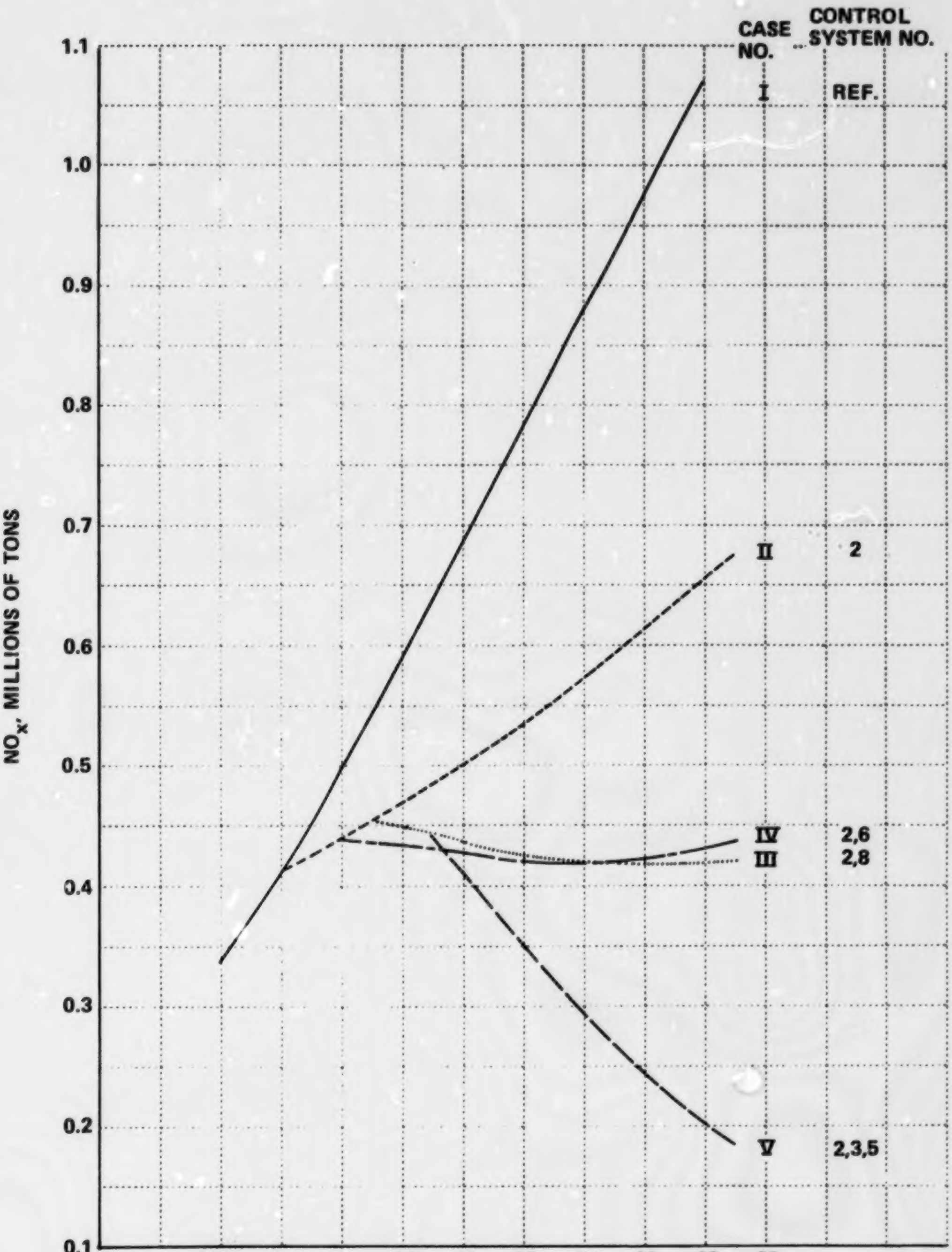

Figure 2.21 ANNUAL NO$_x$ EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY – CONVENTIONAL GASOLINE ENGINES ONLY – MDV

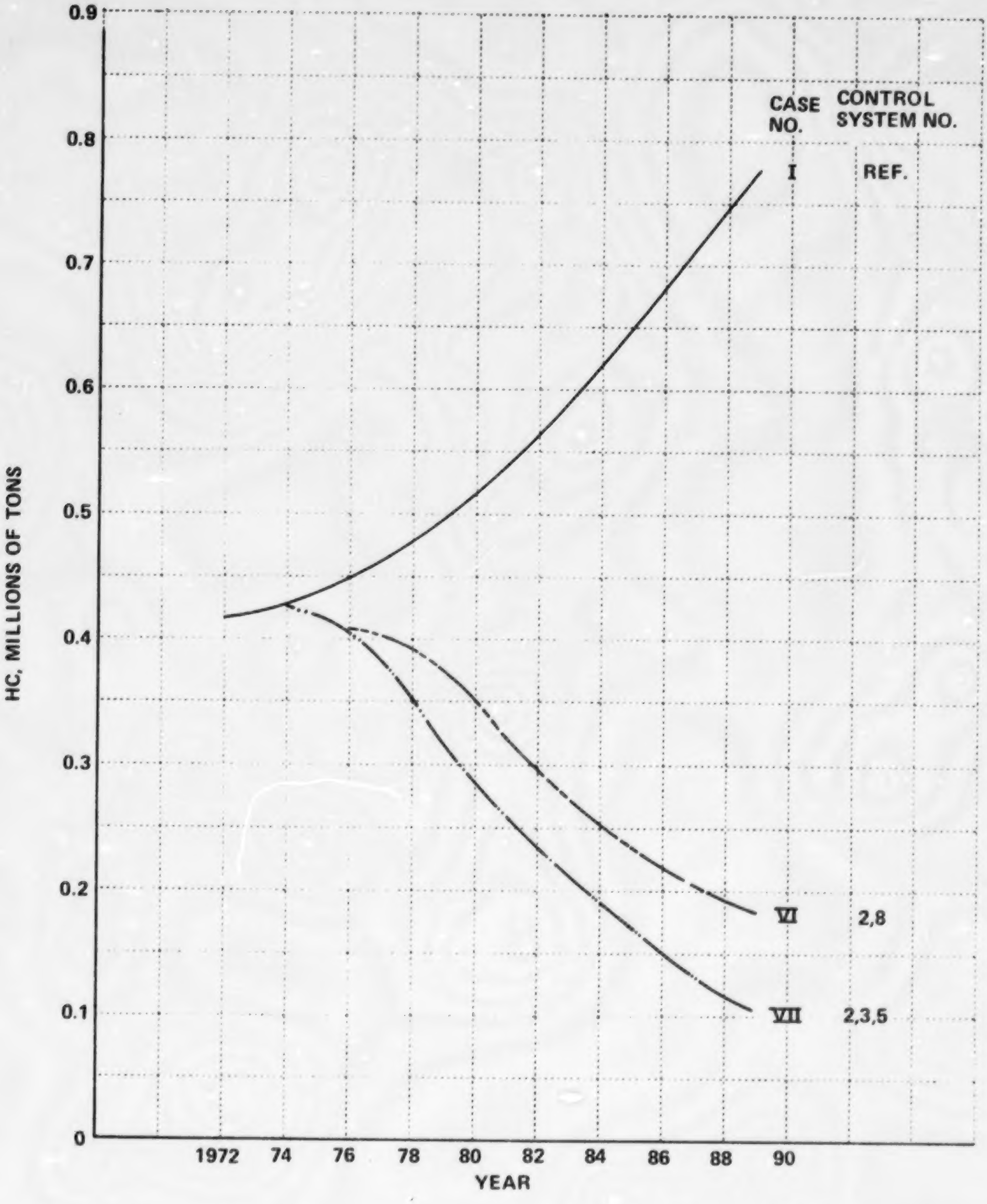

Figure 2.22 ANNUAL HC EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY -- CONVENTIONAL ENGINES AND DIESELS (W/EGR) -- MDV

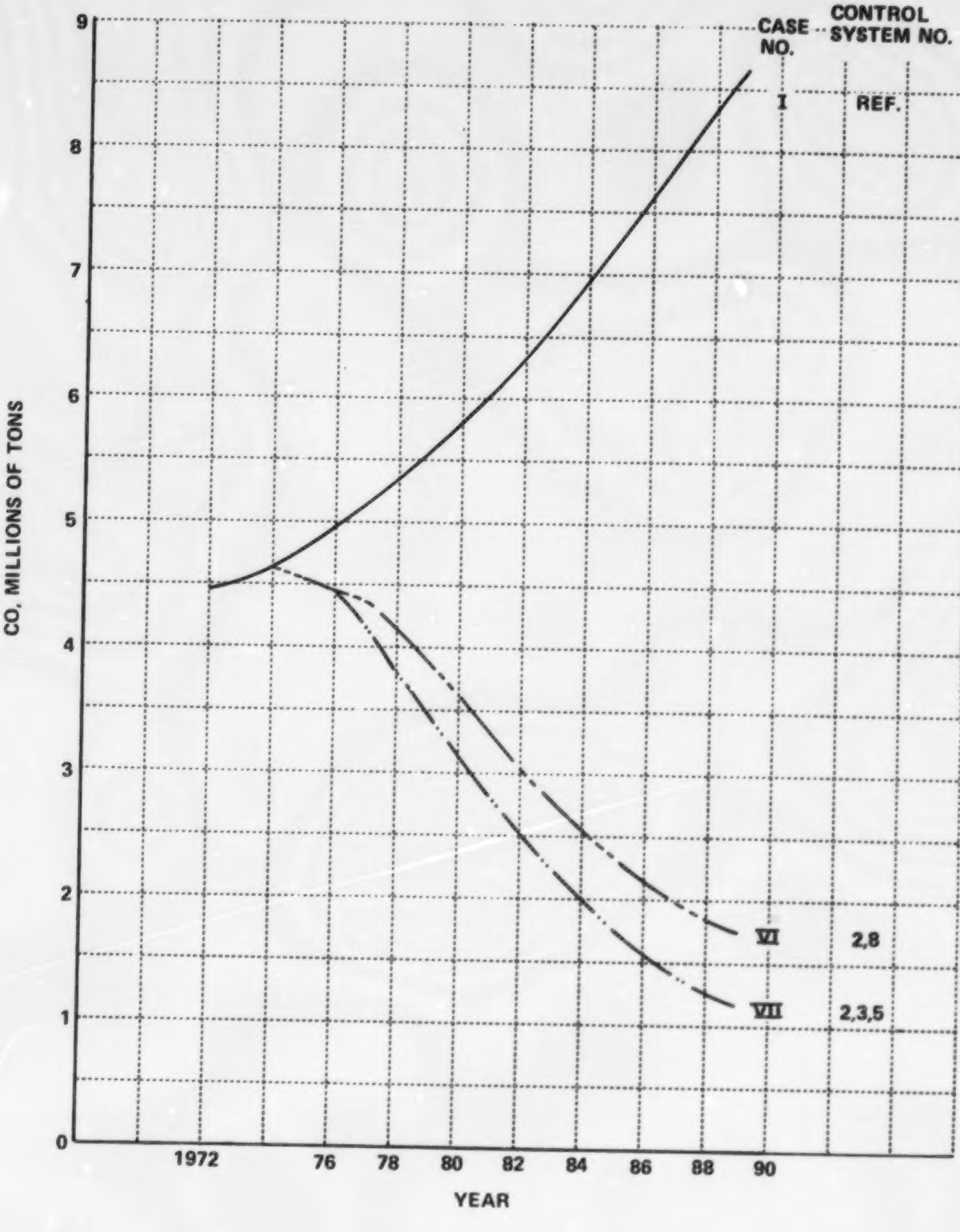

Figure 2.23 ANNUAL CO EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY -- CONVENTIONAL ENGINES AND DIESELS (W/EGR) -- MDV

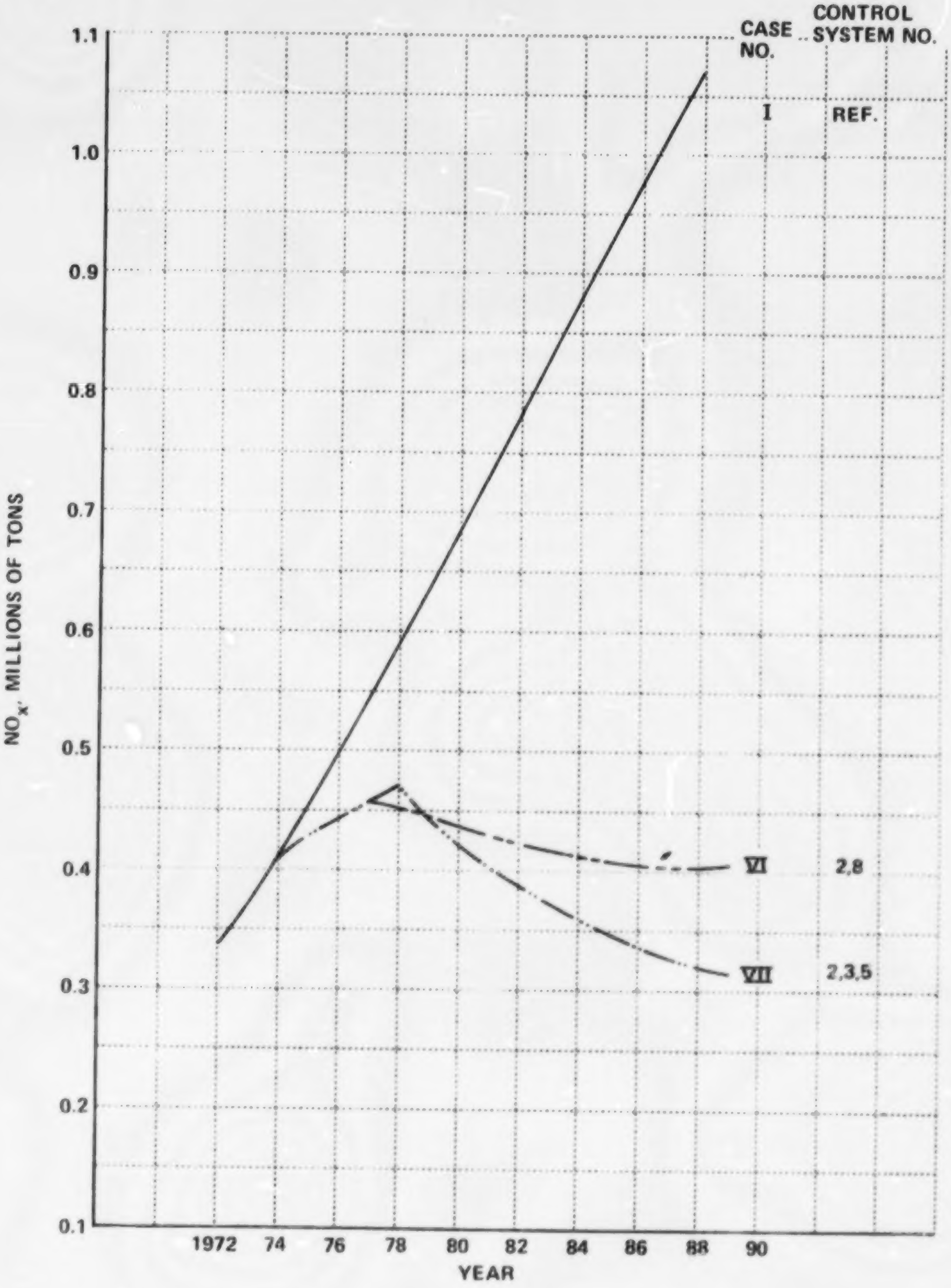

Figure 2.24 ANNUAL NO_x EMISSIONS AS FUNCTIONS OF CONTROL STRATEGY -- CONVENTIONAL ENGINES AND DIESELS (W/EGR) -- MDV

conventional/diesel engines. Because of the very low inherent HC and CO emissions of the diesel engine, it is seen that the combined use of controlled conventional engines and diesels results in lower emissions of these two pollutants than if only controlled conventional engines are used. On the other hand, a homogeneous population of conventional engines equipped with catalytic converters produces lower NO_x emissions than a heterogeneous population of similarly controlled conventional engines and EGR equipped diesels. The reason for this result is that the NO_x emissions from a diesel engine with EGR are higher than those of an equivalent conventional engine fitted with a catalytic converter system (reducing).

A note of interest is the observation that the improved fuel control strategy (comprising control systems No. 2 and 8) is rendered more effective in achieving lower total annual emissions for each of the three pollutants (especially HC and CO) if the heterogeneous engine mix is used. In fact the difference in effectiveness compared with the catalytic converter approach becomes rather small. This fact could be highly significant if the catalytic approach should become unworkable due to developmental obstacles or possible durability problems related to the heavier engine loading of the MDV group.

Figure 2.25 presents a graphical summary of the fuel penalties associated with each of the four control strategies used with the medium duty vehicle group in the situation when only conventional gasoline engines are considered. The ordinate shows the percentage of the total annual fuel consumed which is attributable to the use of the emission control systems.

NOTE: To avoid confusion in dates, it should be observed that the introduction of control systems occurs at the beginning of a designated year while annual emissions are computed over the entire period of the designated year.

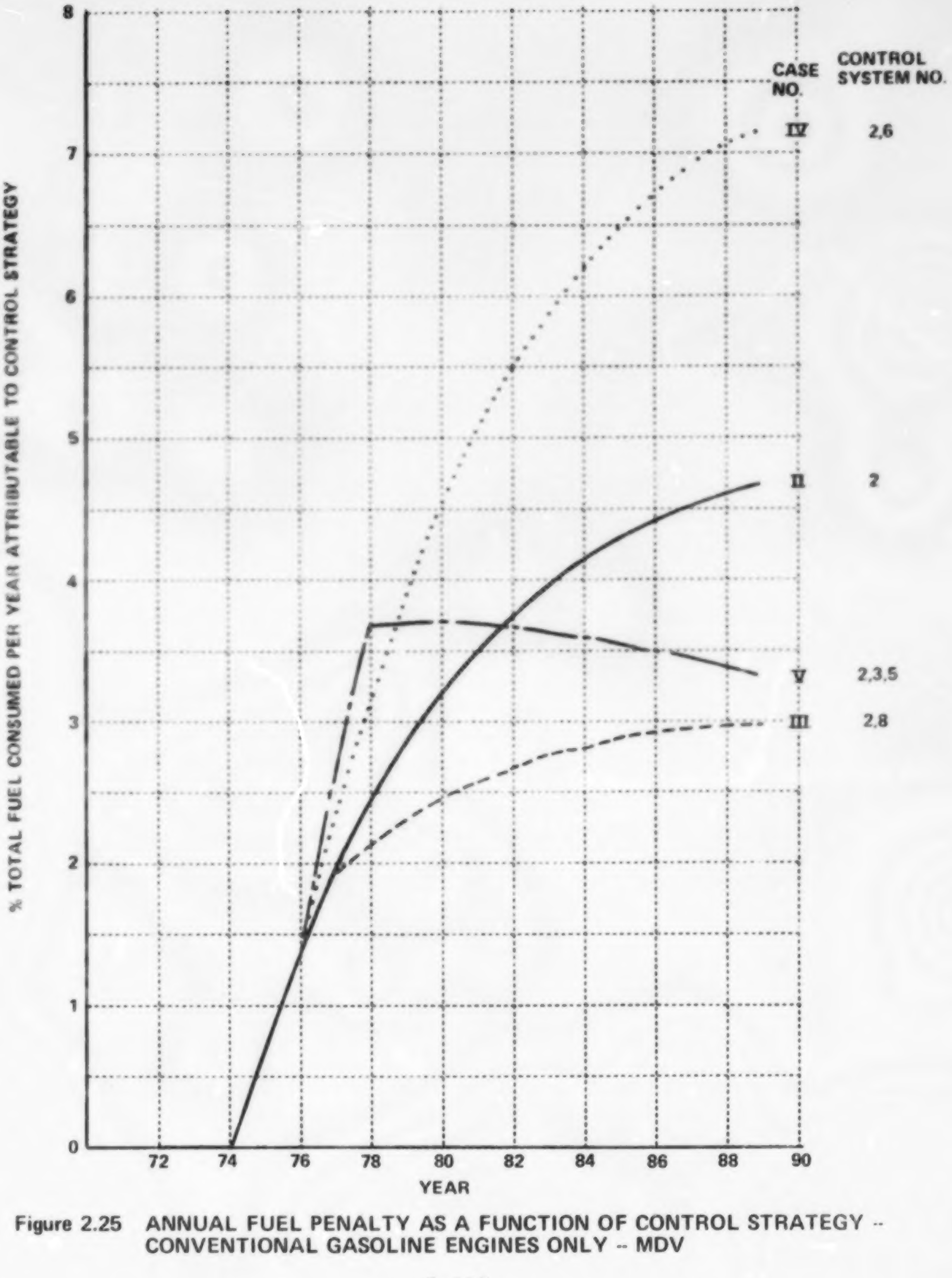

Figure 2.25 ANNUAL FUEL PENALTY AS A FUNCTION OF CONTROL STRATEGY -- CONVENTIONAL GASOLINE ENGINES ONLY -- MDV

Those systems which produce the greatest reductions in emissions are also seen to be the ones incurring the smallest fuel penalties. The sharp break observed in the trace associated with the catalytic control system is explainable by the transition from a system (No. 3) with poor economy to one (No. 5) with a very low fuel penalty. It should be noted that the catalytic system requires the use of lead-free gasoline.

Fuel data corresponding to the heterogeneous engine mix situation is shown in Figure 2.26. In this case we see that a saving in fuel consumption actually occurs when diesels, with their excellent fuel economy, are partially substituted for conventional engines equipped with control systems. The ordinate shows the percentage of fuel conserved. This value was calculated as follows. First the total annual quantity of fuel consumed by the medium duty vehicle group was identified (from the computer printout) for the case of conventional engines only when equipped with each of the control systems identified in Figure 2.26. Similar fuel data was identified for the case of the conventional engine/ diesel engine mix with the same control systems. Subtracting the corresponding set of figures for each year and dividing this difference by the larger base figure gave the percentage value for the fuel conserved. Because the two control strategies considered have substantially equivalent fuel penalties when used with conventional engines, the fuel savings attributable to the use of diesels was found to be almost identical for the two cases. Hence only a single curve is shown in Figure 2.26. While these percentage values may appear small, the quantity of fuel involved is large. For purposes of reference, the annual fuel consumption for the medium duty vehicle group equipped with conventional engines and operating at 1972 baseline fuel economy is shown in Figure 2.27.

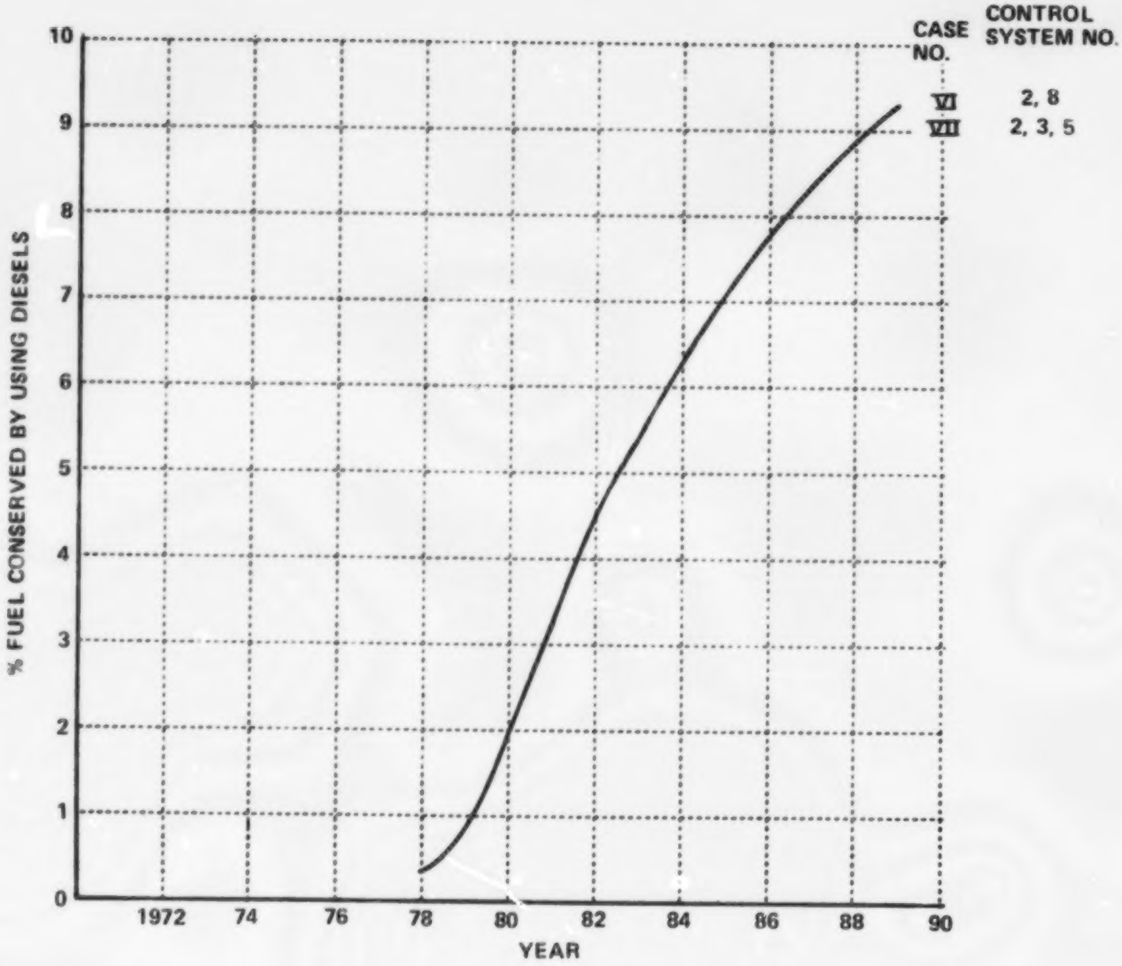

Figure 2.26 ANNUAL FUEL ADVANTAGE USING CONVENTIONAL ENGINE/DIESEL MIX RATHER THAN CONVENTIONAL ENGINES ONLY -- MDV

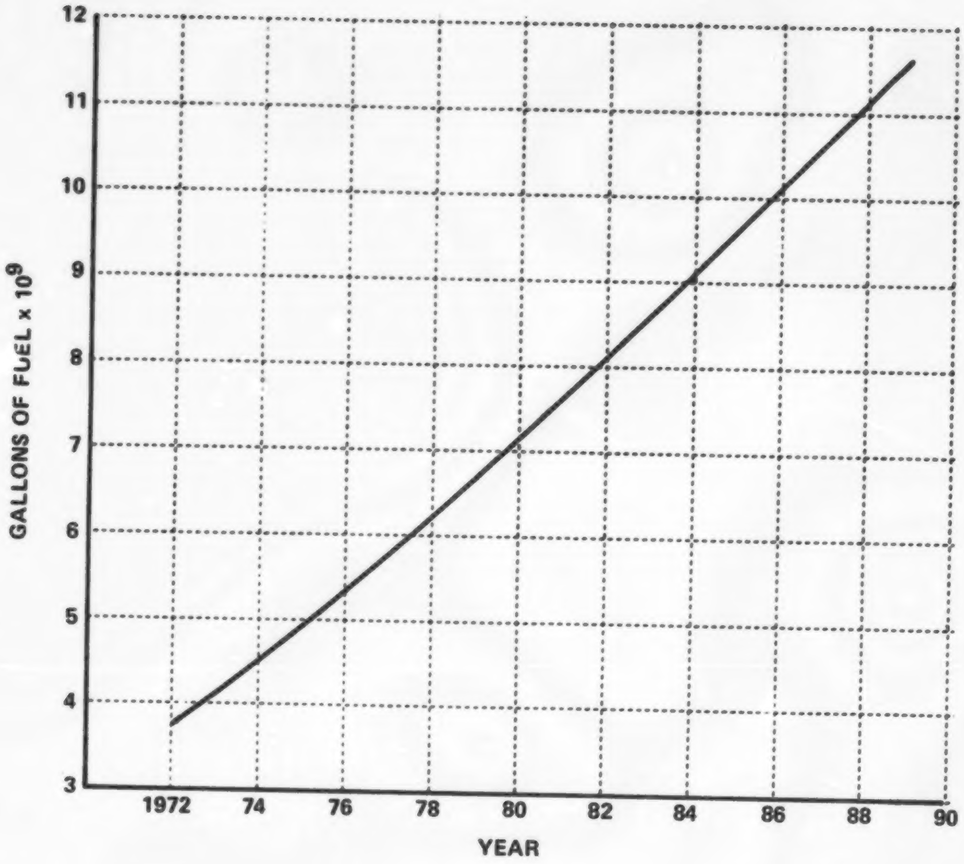

Figure 2.27 REFERENCE ANNUAL FUEL CONSUMPTION FOR MDV -- CONVENTIONAL GASOLINE ENGINES -- NO ADD-ON CONTROL SYSTEMS

The emissions projections show that a sizeable impact on the total annual emissions attributable to the 6,000-14,000 lb. GVW group of vehicles can be achieved in a rather short span of time. Using some of the more effective control strategies, a reduction in emissions of about 40% is predicted by 1980 over the reference situation where all the future production vehicles are presumed to maintain 1972 emission levels.

2.7.5 Control Strategy Evaluation

In a situation where a number of alternative approaches in attacking a problem exist, the normal tendency is to attempt an optimized solution. This is a desirable objective and may be feasible if the specific criteria for optimization are identified. Reduction of the emissions emitted by a class or category of vehicles involves many factors which are interdependent and interact. For example, such factors as level of emissions control, fuel penalty, costs and vehicle performance are inter-related. While each factor may be assigned a "weighting" index to facilitate analysis, such a choice of weighting indexes is completely arbitrary unless circumstances provide a realistic basis for such an assessment. It is therefore more meaningful to discuss a possible "best" approach to emission control of the medium duty vehicle rather than an optimum approach.

The present discussion of a "best" control strategy is presented in the context of the data and information developed in this study. This study has perforce relied on estimated or extrapolated data in situations where experimental information either did not exist or was not available. Also, the computer study was of a lesser scope than would have been desirable. Since costs of implementation were not a part of this study (cost analysis is included in Part B, Section 3.0), this important factor is excluded here.

The results of the computer study provide a rather clear and unambiguous evaluation of the several control strategies which were considered appropriate to the medium duty vehicle. Solely from the standpoint of emission reduction, the control strategy based on the use of catalytic converters with conventional engines is demonstrably superior for HC, CO and NO_x. The fuel penalty is only slightly higher than the most economical (but less effectual) system evaluated.

Further reduction of HC and CO emissions is achieved if a portion of the medium duty vehicle engines equipped with catalysts is replaced with diesels which incorporate an EGR system. In addition, a "bonus" is realized by a substantial savings in the quantity of fuel that is consumed. On the other hand, the introduction of the diesel does incur a lesser control of NO_x.

The use of the diesel engine as a part of the control strategy places the improved fuel control approach as an excellent alternative to the catalytic converter route. While the emission reduction is somewhat poorer, a fuel "bonus" is realized and the durability will undoubtedly be superior to the catalytic converters.

The "best" control strategy, defined as achieving a high reduction of emissions combined with a low fuel penalty, is that utilizing a blend of conventional engines equipped with catalysts and diesel engines equipped with EGR. A likely alternative choice is that wherein the improved fuel system approach is substituted for catalysts.

Diesels are usually associated with exhaust smoke and odor. While the pre-chamber diesel achieves better control over these exhaust characteristics, the possibility exists that concentrations of large numbers of diesels in urban areas may create objectionable problems with regard to smoke and odor.

3.0 ECONOMIC ANALYSIS PART B

3.1 Introduction and Summary

The purpose of the study is to develop and analyze the relationships between different control levels and the cost-of-ownership of representative 6-14,000 lbs. GVW vehicle-engine types equipped with various engine-emission control systems. The time span of interest is 1972-1980. The term cost-of-ownership is defined as the cost to the final vehicle user. The economic analysis is part of the preceding study program which entailed a technical evaluation of emission control approaches and an assessment of emission limits for 6-14,000 lbs. GVW vehicles.

Projected sales of the various types of vehicles which comprise the 6-14,000 lbs. GVW vehicle population are developed in section 3.3. The vehicles within this GVW range are divided into two weight categories; 6-10,000 lbs. and 10-14,000 lbs. The vehicles in the first category predominate. In recent years they have represented 20-24 percent of all U.S. sales of trucks and buses. Sales of the 10-14,000 lbs. vehicles have generally accounted for less than 2 percent of total U.S. sales.

The derivation of the costs of the proposed emission control devices is described in section 3.4. Diesel engine costs are also included in this section. The cost estimates are incremental costs relative to the 1972 spark ignition engines. Because of the uncertainties associated with a number of the devices, cost bounds are developed representing low, anticipated and high cost estimates.

Emission control system costs are synthesized in section 3.5. Eight systems for use with spark ignition engines and two diesel engine systems are considered. Separate costs are first shown for each of the three major cost categories: initial or sticker prices, incremental maintenance and operating costs. These costs are then combined into total costs representative of 50,000 miles or 5 years of vehicle operation.

The resultant costs vary widely. The systems which employ catalytic converters to control pollutants have the highest costs. Diesel engines, despite their relatively high initial cost, offer long term savings relative to the baseline engine because of their lower fuel consumption.

The emission control alternatives considered are presently in varying stages of development. Estimated lead times for the systems are discussed in section 3.6. They vary from about 2 to 5 years for systems designed for use with spark ignition engines. The development of a domestic family of diesel engines is estimated to require 8-10 years. The production of one diesel engine with relatively wide applicability to medium duty vehicles could be achieved sooner, by 1978 or 1979.

The costs and effectiveness of the systems are examined in section 3.7. Three approaches or control strategies are delineated for conventional gasoline engines. These are defined according to their major emission control device. They are improved carburetion, thermal reactor, and catalytic converter. The strategies are not mutually exclusive. For example, improved carburetion features are also used with thermal reactors and catalytic converters.

The greatest reduction of pollutant emissions is achieved with catalytic converters. The cost incurred, however, is high. A mix of diesel powered vehicles, equipped with EGR and spark ignition powered vehicles with improved carburetion provides almost the same level of emission control at significantly lower costs. The latter combination appears as the "best" approach based on the analysis performed.

A gross estimate of the potential impact of certification costs is made in section 3.7.1. The final section discusses the potential impact of the costs of emission control systems on the lease costs of such vehicles.

3.2 Conclusions

The conclusions of the study are:

1. The use of improved carburetion for emission control of spark ignition engines together with the introduction of diesel engines appears as the best control strategy for medium duty vehicles. This approach would reduce annual emissions of HC, CO and NO_X by 77, 81 and 64 percent (compared to 1972 baseline), respectively by 1989. The 15 year cost of this approach is $2 billion.

2. A small, further improvement in NO_X emission reductions can be obtained by a mix of diesel and standard gasoline engines where the latter are equipped with catalytic converter systems. The 15 year cost of this approach is considerably higher, $3.4 billion.

3. Diesel engines equipped with EGR result in significant emission reductions and at the same time provide good fuel economy. Fuel savings more than off-set the higher initial price of such engines.

4. The improved carburetion and catalytic converter approaches are the systems of choice in the absence of diesel engines. Implementation of the former systems will result in the reduction of all pollutants by about 60 percent by 1989 at a total cost of $3.7 billion. The latter systems will reduce emission levels of HC by 79, CO by 72 and NO_X by 83 percent by 1989. The cost incurred, however, is $5.3 billion.

5. Lean thermal reactor and improved carburetion strategies result in about equal effectiveness. The former costs more, primarily because of the higher fuel penalty associated with it.

6. Precise estimates of certification costs cannot be made until the requirements, engine families and vehicle types are firmly defined. A preliminary analysis indicates, however, that the potential impact of certification costs could be significant, particularly for the smaller manufacturers.

7. The cost per mile of operation of pollution control systems is generally less than $.01 per mile. The potential impact of this cost on lease charges is, therefore, not considered significant.

3.3 Sales Projections for 6-14,000 GVW Vehicles

3.3.1 Introduction

The vehicles within this GVW range fall into two clearly demarked weight cateogries; 6-10,000 lbs. and 10-14,000 lbs. The vehicles in the 6-10,000 lbs. GVW category predominate. In recent years they have accounted for 20-24 percent of all U.S. sales of trucks and buses. Sales of vehicles in the 10-14,000 lbs. GVW category have always represented less than 2 percent of total sales, and in many years less than one half of one percent.

In recognition of this sharp distinction, sales projections are made separately for the two weight categories of vehicles. All data employed, unless noted otherwise, are obtained from information published by the Motor Vehicle Manufacturers Association of the U.S., Inc.

3.3.2 Sales Projections for 6-10,000 lbs. GVW Vehicles

Total U.S. sales of trucks and buses are shown in Figure 3.1. A least square curve is fitted to the data and extended to 1980. The broken lines represent $\pm 1\ \sigma$ values. Computation was done as follows:

$$\sigma = \sqrt{\frac{(x-\bar{x})^2}{(N-2)}}$$

Annual sales are estimated to increase from 2.5 million in 1973 to 3.1 million in 1980.

Comparable data for 6-10,000 lbs. GVW vehicles are shown in Figure 3.2. Visual inspection shows that a straight line may not provide the best indicator of future sales. The most recent data (1972) indicates a sharp rise in the sales of these vehicles. Thus, the straight line projection would tend to underestimate future sales if this trend continues. An alternative projection was, therefore, made which takes this recent trend into account.

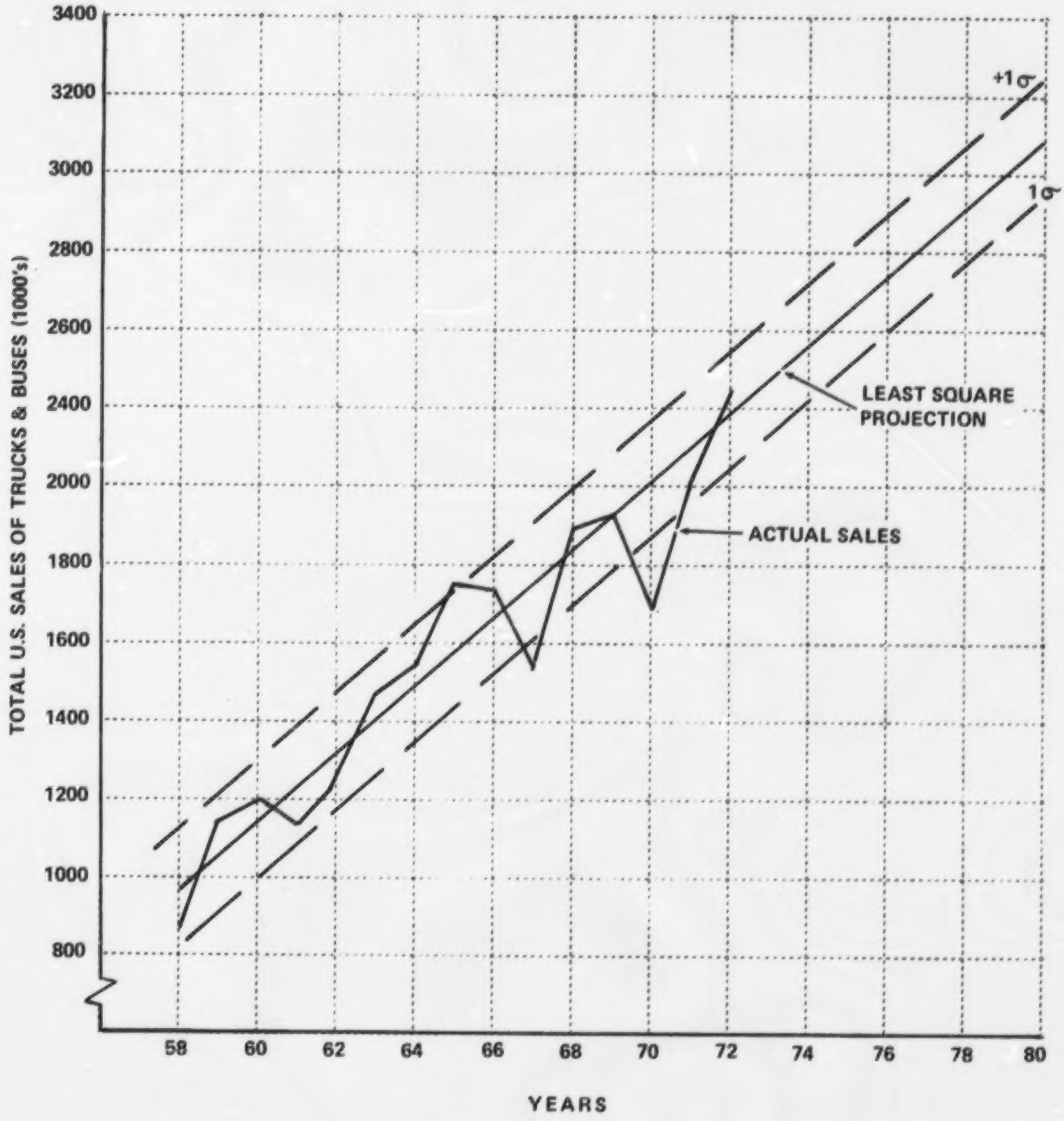

Figure 3.1 U.S. SALES OF TRUCKS AND BUSES

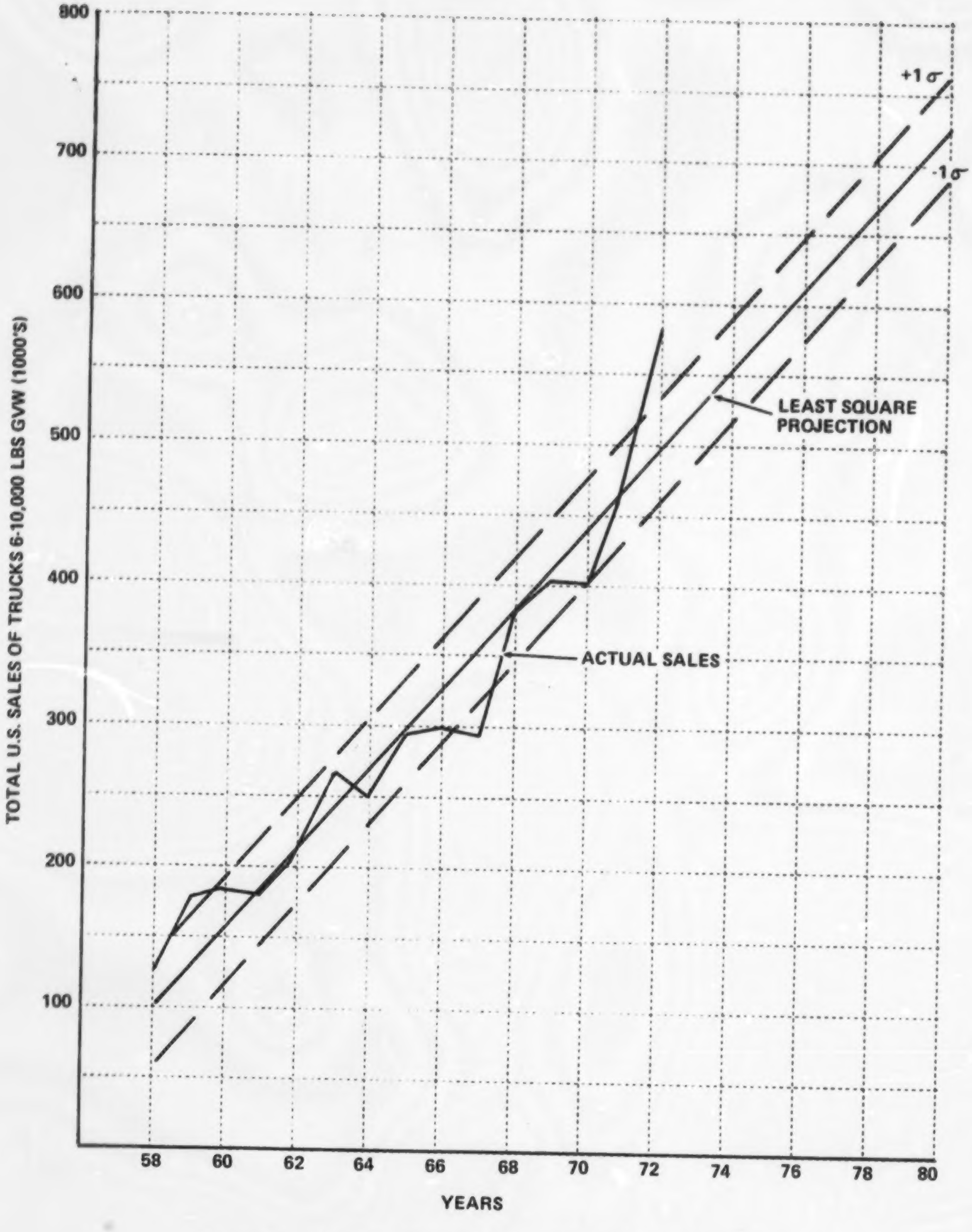

Figure 3.2 U.S. SALES OF 6-10,000 LBS GVW TRUCKS

Initially, the percent of 6-10,000 lbs. GVW truck sales of total truck sales were computed and projected through 1980 (Figure 3.3). Next, the percentages from this regression line were multiplied by corresponding values from the regression line in Figure 3.1 for each year. The resultant values are plotted in Figure 3.4. They form the parabolic curve. The straight line in Figure 3.4 is the regression line from Figure 3.2. The two projections compare very closely until 1972 where they begin to diverge.

The two lines bound our estimate of sales of 6-10,000 lbs. GVW vehicles for the 1973-1980 time frame. The combined U.S. manufacturers' estimate of 1973 sales for this category of vehicles is about 565,000 units. The parabolic projection yields an estimate of 540,000 units, the straight line projection about 527,000 units.

3.3.2.1 Sales Projections by Body Types

Four body styles are included in the study: Pickups, Van/Panel trucks, Multistop vans, and Cab/Cowl/Base Chassis and Platform trucks. Together they account for more than 90 percent of the vehicles in the 6-10,000 lbs. GVW weight category. The remainder consists of passenger and special purpose vehicles which are outside the scope of the study.

Existing data do not permit a separate breakout of recreational vehicles. In fact, all body styles are used for this purpose. Recreational vehicles are discussed separately in Section 3.3.4.

The percent of sales of 6-10,000 lbs. GVW trucks by body types is shown in Table 3.1 for the years 1966-1971.

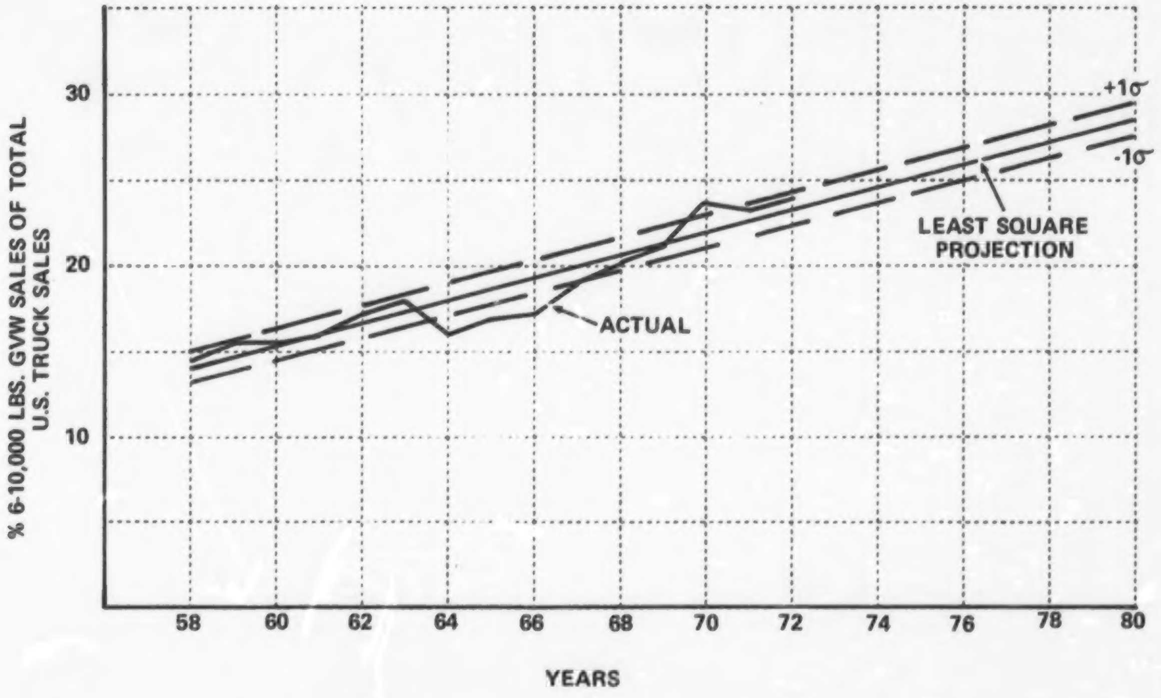

Figure 3.3 % 6-10,000 LBS GVW TRUCK SALES OF TOTAL U.S. SALES OF TRUCKS AND BUSES

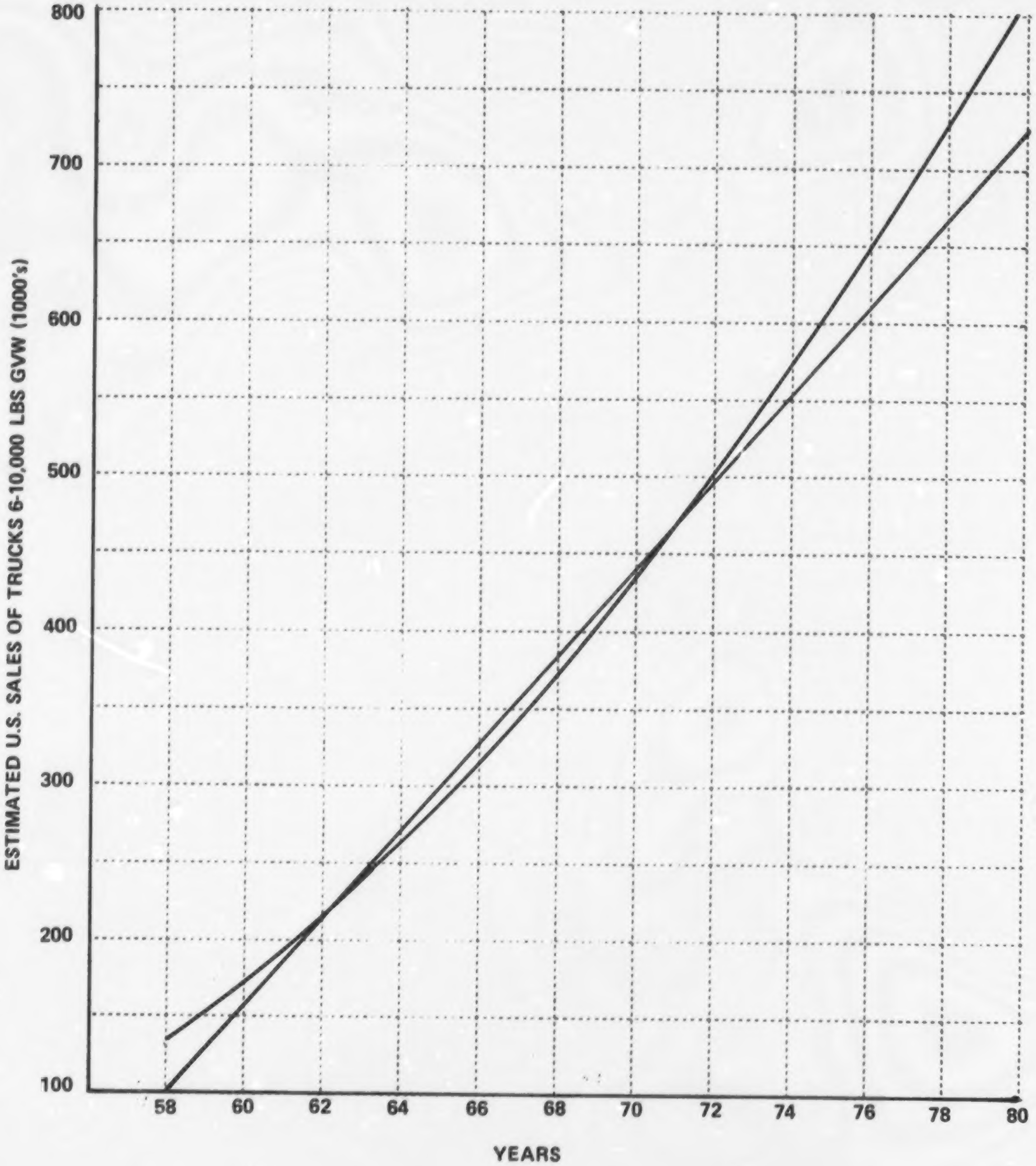

Figure 3.4 ESTIMATED U.S. SALES OF 6-10,000 LBS GVW TRUCKS

Table 3.1 Percent of U.S. Sales of Trucks by Body Types

Year	Pickup	Van/Panel	Multistop Van	Chassis
1966	64.2	1.0	8.0	26.4
1967	64.3	3.0	9.0	21.4
1968	69.9	2.0	7.0	19.0
1969	63.9	3.8	9.7	21.1
1970	56.0	12.4	8.5	21.7
1971	57.5	13.5	7.1	15.3

The fraction of vehicles in this weight category which are pickups has declined in recent years. The projection for this body style as a percent of total sales in this weight category is shown in Figure 3.5. The resultant sales projections are presented in Figure 3.6. They are computed by multiplying the percentages in Figure 3.5 by the two sales projections shown in Figure 3.4. Although the number of pickup trucks as a percent of total sales is expected to decline slightly, the number of units sold is shown to increase, reaching sales of 400,000-450,000 units by 1980.

The sales of the other body types are estimated on the basis of the following factors.

Body Type	% of Sales of 6-10,000 lbs. GVW Vehicles
Van/Panel	14
Multistop	8
Chassis	18

The resultant sales projections, computed as indicated above, are shown in Figures 3.7, 3.8 and 3.9.

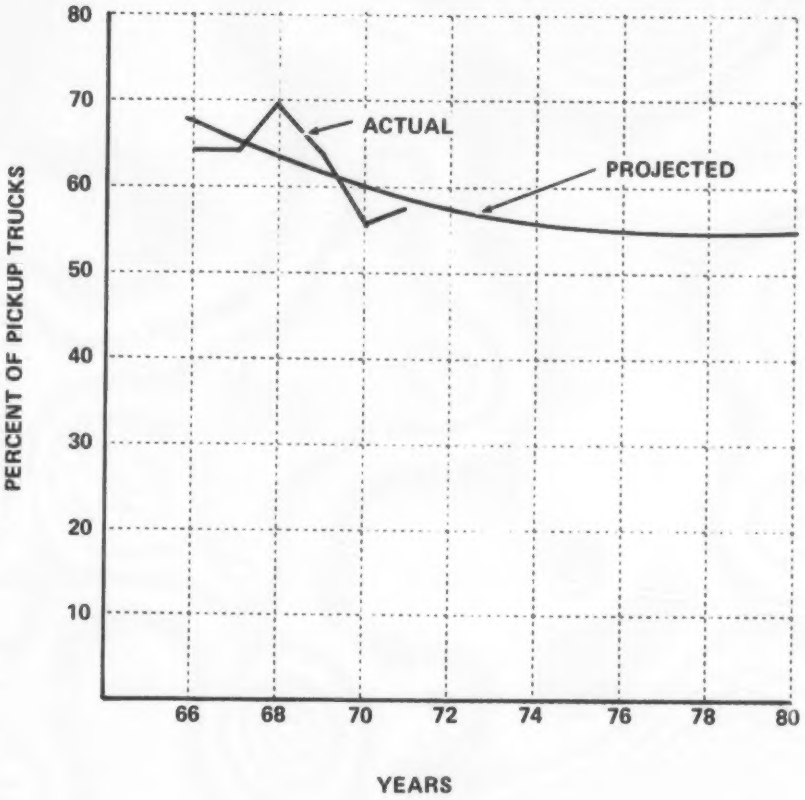

Figure 3.5 % U.S. SALES OF PICKUP TRUCKS OF TOTAL SALES OF 6-10,000 LBS GVW TRUCKS

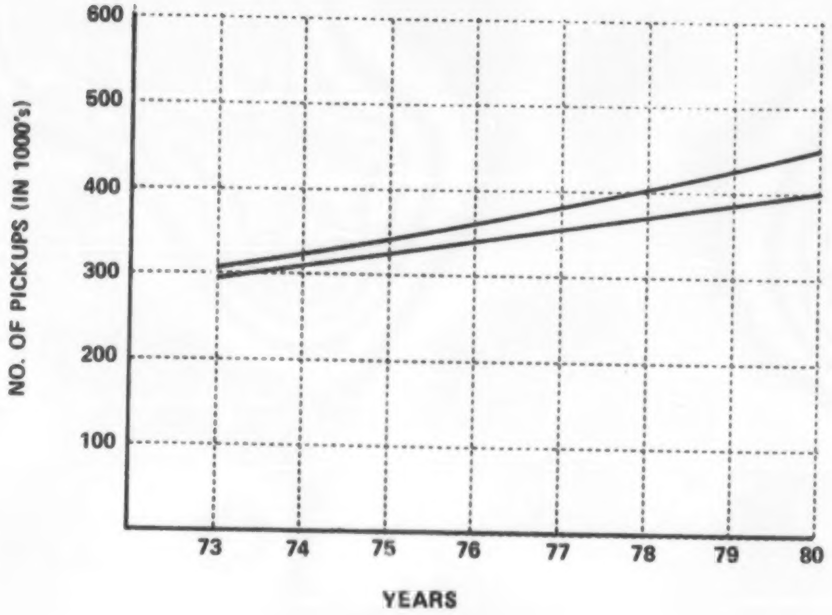

Figure 3.6 PROJECTED SALES OF PICKUP TRUCKS

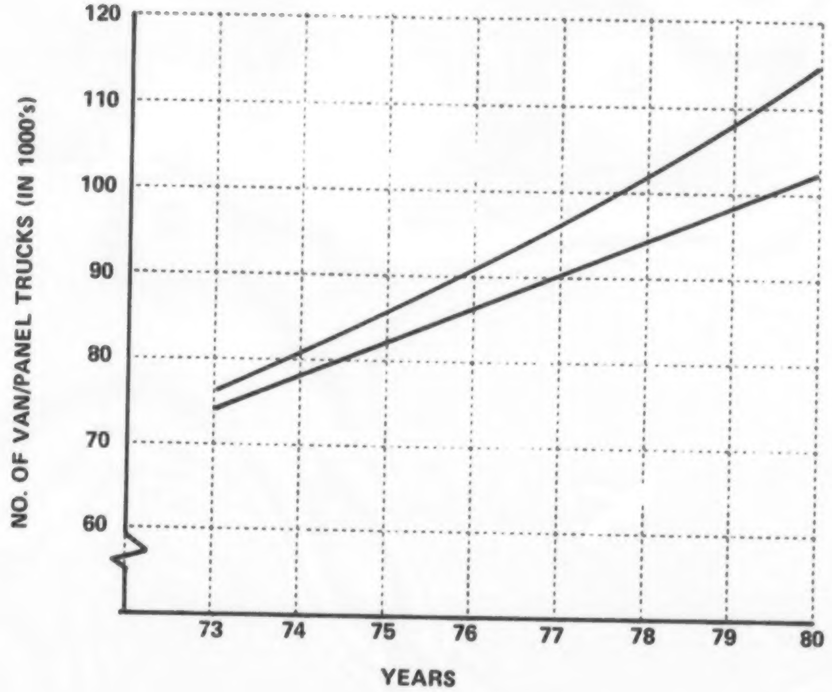

Figure 3.7 PROJECTED SALES OF VAN/PANEL TRUCKS

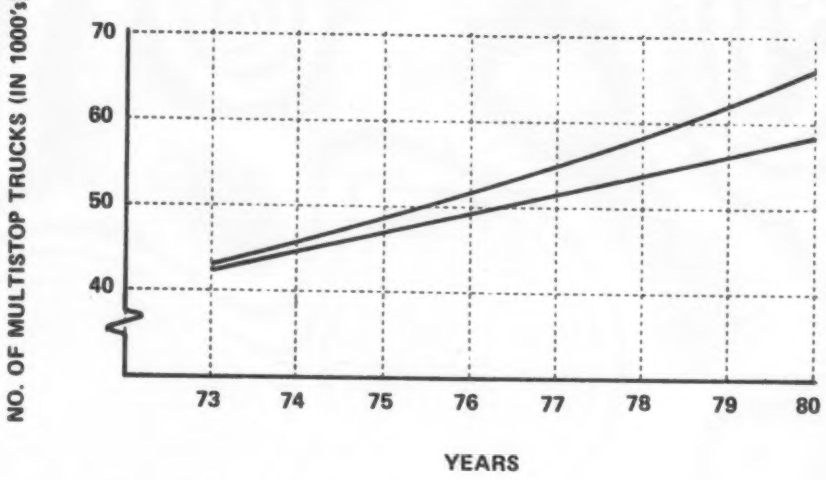

Figure 3.8 PROJECTED SALES OF MULTISTOP VANS

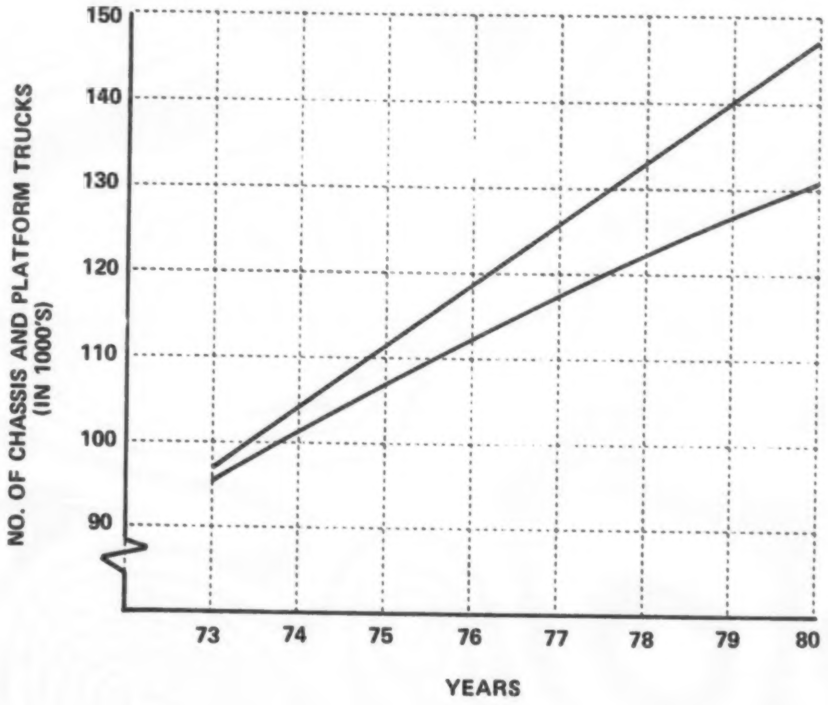

Figure 3.9 PROJECTED SALES OF CHASSIS AND PLATFORM TRUCKS

Shifts in preference for a particular body type, particularly in its application as a recreational vehicle can alter the relative percentages and sales projections. The latter three body types, Van/Panel, Multistop and Chassis appear most sensitive in this respect and the sales projections must be considered accordingly.

3.3.3 Sales Projections for 10-14,000 GVW Vehicles

Sales of these vehicles for 1958-1972 are shown in Figure 3.10. Historically, these vehicles have comprised only a very small percentage, less than 2 percent, of total U.S. sales of trucks and buses. The past two years, however, have witnessed a relatively large growth of sales of vehicles in this category, with 1972 sales amounting to about 45,000 units. This increase is believed attributable largely to the growing popularity of recreational vehicles, particularly of motor homes.

The sales projections shown by the broken lines in Figure 3.10, are based on percentages of total U.S. sales of trucks and buses. The three projections represent sales of vehicles in this weight categories amounting to 2, 4 and 6 percent, respectively, of total sales shown in Figure 3.1. Our best estimate is that the 4 and 6 percent lines bound projected sales for the 1973-1980 period. Manufacturers' estimates place sales of vehicles in this category at about 100,000 units in 1973. This represents 4 percent of the estimated total sales of all trucks and buses.

3.3.3.1 Sales Projections by Body Types

Vehicles in the 10-14,000 lbs. GVW category consist primarily of two body types -- multistop van and chassis. No pickups or van/panel trucks of this weight are manufactured. The proportion of the two body types sold between 1966 and 1970 is shown in Table 3.2.

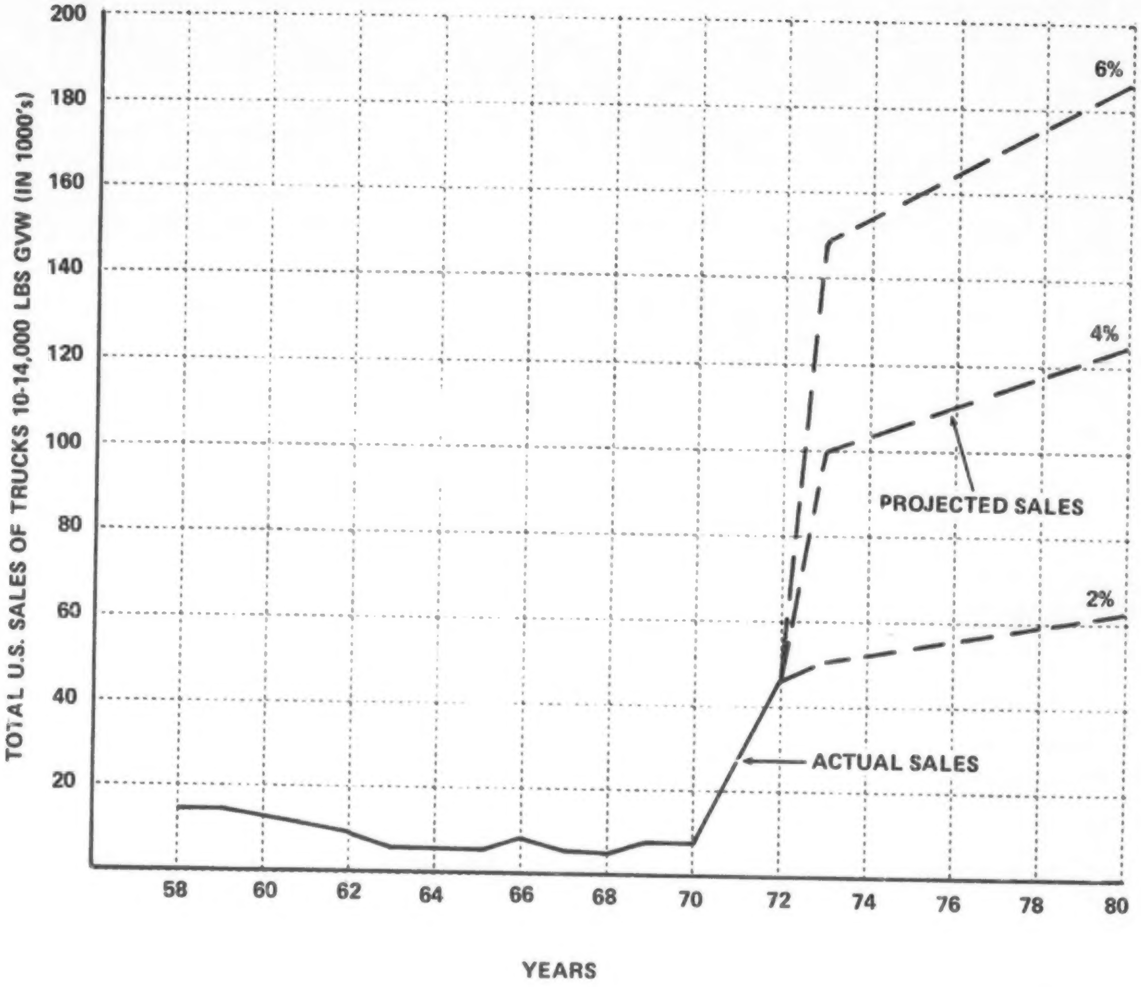

Figure 3.10 U.S. SALES OF 10-14,000 LBS GVW TRUCKS

Table 3.2 Percent of Sales of 10-14,000 lbs. GVW Vehicles by Body Type[1]

Year	Multistop Van	Chassis
1966	43.5	55.3
1967	51.2	48.2
1968	42.7	57.0
1969	59.9	39.7
1970	46.7	53.1

No trend is discernible. A 50-50 split between these body types appears a reasonable estimate. Both body types are used for recreational vehicles. The relative proportions of each type used for this purpose are not known.

3.3.4 Recreational Vehicles

All the body types noted in the previous sections can be and are used as recreational vehicles. Recreational vehicles can be divided into two general categories -- truck campers and motor homes. Truck campers represent numerically the larger of the two categories. They consist of camper bodies mounted on pickup or chassis trucks. Such vehicles are frequently multipurpose in use. They may be employed for personal transportation or commercial use and converted to recreational vehicles when desired. Motor homes generally are used only as recreational vehicles. In the past, they have been fabricated by motor home manufacturers on chassis purchased from automobile manufacturers.

Recent sales of recreational vehicles are shown in Table 3.3. The sales data base used is from "Recreational Vehicles Facts and Trends".

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[1] 1971 data will not be available until June 1973.

Table 3.3 Sales of Recreational Vehicles

Year	Truck Camper	Motor Home	Total	% of 6-14,000 GVW Vehicle Sales
1967	61,600	9,050	70,650	23.9
1968	79,500	13, 00	92,700	23.7
1969	92,500	23,100	115,600	28.0
1970	95,900	30,300	125,200	30.6
1971	107,200	57,200	164,400	33.4

All of the vehicles are in the 6-14,000 lbs. GVW range. Past and projected future sales of such vehicles are included in the sales projections contained in the previous sections.

One third of all vehicles in the 6-14,000 lbs. GVW range were used, at least partly, as recreational vehicles in 1971. Sales of such vehicles more than doubled between 1967 and 1971 demonstrating their increasing popularity. This trend is expected to continue over the next few years. Beyond that, their sales will be strongly influenced by the state of the economy, and more specifically by the development of new recreational areas and facilities to meet the demands of these types of vehicles.

3.3.5 Engines Used in 6-14,000 lbs. GVW Vehicles

Engine data for the vehicles is based on manufacturers' sales projections for 1973. Engines are divided into the following 5 categories for this analysis:

I6	225-250 CID
I6	250-300 CID
V8	300-320 CID
V8	330-360 CID
V8	390-500 CID

All major manufacturers produce engines in each of the V8 categories. Additionally, each manufacturer offers at least one I6 engine option.

The manufacturers' sales projections do not permit a clear-out categorization by body type. Consequently, the totals represent more valid bases for comparison than the numbers shown for the individual body types. The data are shown in Table 3.4.

The V8-330-360 CID engine predominates in 6-10,000 lbs. GVW vehicles. This is due largely to its extensive use in pickup and chassis trucks. Van/Panel and multistop vans are frequently sold with smaller engines as well.

The distribution of engines in the 10-14,000 lbs. GVW vehicles is somewhat different. The largest V8 is the most common engine due to its extensive use in motor homes. The second engine in order of usage is the small V8 300-320 CID.

Table 3.4 Engines in 6-14,000 lbs. GVW Vehicles Based on 1973 Manufacturers' Sales Projections

	I6 225-249	I6 250-300	V8 300-320	V8 330-360	V8 390-500
6-10,000 lbs GVW Vehicles					
Pickup and Chassis	9,680	23,982	62,630	346,247	62,797
Van/Panel Trucks	2,000	2,591	23,320	24,000	
Multistop Vans	1,000	1,000		3,000	
Motor Homes					3,850
Subtotals	12,680	27,573	85,950	373,247	66,647
10-14,000 lbs. GVW Vehicles					
Chassis	250	4,478	1,200	4,754	200
Multistop Vans	2,000	4,700	2,000	12,850	5,000
Motor Homes			22,870		28,130
Subtotals	2,250	9,178	26,070	17,604	33,330
GRAND TOTALS	14,930	36,751	112,020	390,851	99,977

3.4 Cost Estimates

3.4.1 Introduction

Incremental sticker prices and maintenance costs of the emission control devices employed with the spark ignition engine are developed in this section. Additionally, incremental costs associated with diesel engines are presented. The cost baseline is the 1972 spark ignition engine incorporating engine modifications but without add-on devices.

Firm cost information concerning emission control devices presently in use on light duty vehicles is not readily available. The cost increment resulting from the addition of these devices is included in the total current automobile prices.

The devices proposed for use on medium duty vehicles include some which are similar to those presently employed on light duty vehicles as well as others which are in various stages of development. Consequently, the cost estimates presented in this section are preliminary and must be reexamined as further information becomes available.

The approach taken has been to establish a consistent set of costs; particularly with respect to the relative cost differences between systems. Because of the uncertainties associated with the costs of a number of the devices, cost bounds are developed indicative of low (L), projected anticipated (A), and high (H) costs.

3.4.2 Emission Control Devices

The emission control devices employed in the eight systems are listed in Table 3.5. Costs of the devices are described in the sections following.

Table 3.5 Emission Control Devices

Device	Designation
Electronic ignition	EI
Fast choke	FC
Quick heat intake manifold	QHI
Improved carburetion	IC
Advanced carburetion	FIC
Electronic fuel injection and control	EFIC
Exhaust gas recirculation	EGR
Air injection at exhaust ports	AI
Variable air injection	AI/CAI
Oxidizing catalytic converter	OC
Reducing catalytic converter	RC
Three-way catalytic converter with O_2 sensor	OC/RC+OS
Lean thermal reactor	LTR
Rich thermal reactor	RTR
Oxidizing catalyst bypass system	OCBP
Evaporative control	EC
Emission test	ET

3.4.2.1 Electronic Ignition (EI)

Chrysler Corporation, in 1972, offered electronic ignition as an optional feature at a cost of $34. The introduction of this feature as a standard item should reduce its cost to the customer. It is estimated that savings will be in the order to 25-50 percent resulting in the following costs: (L) = $15, A = $20, H = $25.

Although electronic ignition is expected to have a higher initial cost, net savings in maintenance costs are anticipated. Distributor points do not have to be replaced and less frequent checks of timing and spark plug wires will have to be made. The maintenance cost savings resulting from electronic ignition together with the use of unleaded gas are estimated to amount to $60 over 50,000 miles.(1) The part of the savings attributable to the unleaded gas cannot be readily identified.

3.4.2.2 Fast Choke (FC)

This item is estimated to cost $5 for light duty vehicles by a number of reference sources.(2),(3),(4) There is no evidence that the same device cannot be used on medium duty vehicles. This cost is, therefore, used here. There are no incremental maintenance costs with the fast choke.

3.4.2.3 Quick Heat Intake Manifold (QHI)

The cost of this device is estimated to be the same, $5, as that of the fast choke (FC) noted in the previous Section 3.4.2.2.

3.4.2.4 Improved Carburetion (IC)

Improved carburetion provides for altitude compensation and better air/fuel ratio control. We estimate the incremental costs of these modifications to be L = $5, A = $10 and H = $15.

Reference (5) indicates an incremental maintenance cost of $15 over 50,000 miles for these features, which cost is used here.

3.4.2.5 Advanced Carburetion (FIC)

This device is not sufficiently defined to provide a basis for an independent cost estimate. In the absence of data, the cost assigned to advanced carburetion is 3 times the cost of the improved carburetor (IC), $45, both for the initial sticker price and the maintenance cost.

3.4.2.6 Electronic Fuel Injection and Control (EFIC)

Reference (2) indicates an initial cost of $98 for this device. Telcons with Volkswagen of America(6) and Bendix(7) provided estimates of $100-$200 for this device. The latter, however, apparently do not account for credits for items which are replaced by this device. The costs employed are L = $75, A = $100, and H = $125.

Nozzles are estimated to require replacement every 50,000 miles.(2) Nozzle costs are $2 each.(2) Assuming one hour of labor at $12/hr. is required for nozzle replacement, this yields a cost of $24 for I6 and $28 for V8 engines.

3.4.2.7 Exhaust Gas Recirculation (ERG)

Discussion with Ford Motor Co.(8) indicated that essentially the same device is used on all present engines. It is assumed that the same device can be used on medium duty vehicles. Estimated costs in References (2), (3) and (4) provide a range $25-$47. Another report(9) shows a cost of $7.40. The costs used in this study are L = $20, A = $30 and H = $40.

Maintenance EGR costs are based on Reference (9). They consist of a filter change every 10,000 miles equivalent to an oil filter change. This cost is estimated to be $4.

3.4.2.8 Air Injection (AI)

References (2), (3) and (4) show a range of $29-$46 for air injection with an average cost of $38. There may be a small variation in the size of air pumps required for the different size engines. We do not believe that this change will have a significant impact on costs. We assume that the $38 cost is for a V8 engine. The cost of air injection for the I6 engine is estimated to be $36.

There is no existing data for AI maintenance costs. It is assumed that some maintenance and parts are required every 25,000 miles and that one half hour of labor is required for this maintenance action. Costs of $9 and $10, respectively, are included for I6 and V8 engines.

3.4.2.9 Variable Air Injection (AI/CAI)

This device is similar to that described in Section 3.4.2.8 except for the addition of 1 valve costed at $1. This results in a cost of $39 for V8 engines and $37 for I6 engines. The maintenance cost is assumed to be the same as that for AI.

3.4.2.10 Oxidizing, Reducing and Three-Way Catalytic Converters (OC,RC,OC/RC)

We cannot discern any differences between the two types of converters which should result in differences in costs between the two, assuming that both are the same size. This conclusion is supported by the Aerospace Corp. report(4) in which it is stated that the manufacture of noble and base metal catalysts would result in the same costs.

Experiments are in progress in which large volume catalytic converters (catalyst bed = engine CID) are tested on medium duty vehicles. Estimated converter costs as a function of catalyst bed volume, based on verbal data obtained from U.O.P.(10) is shown in Figure 3.11.

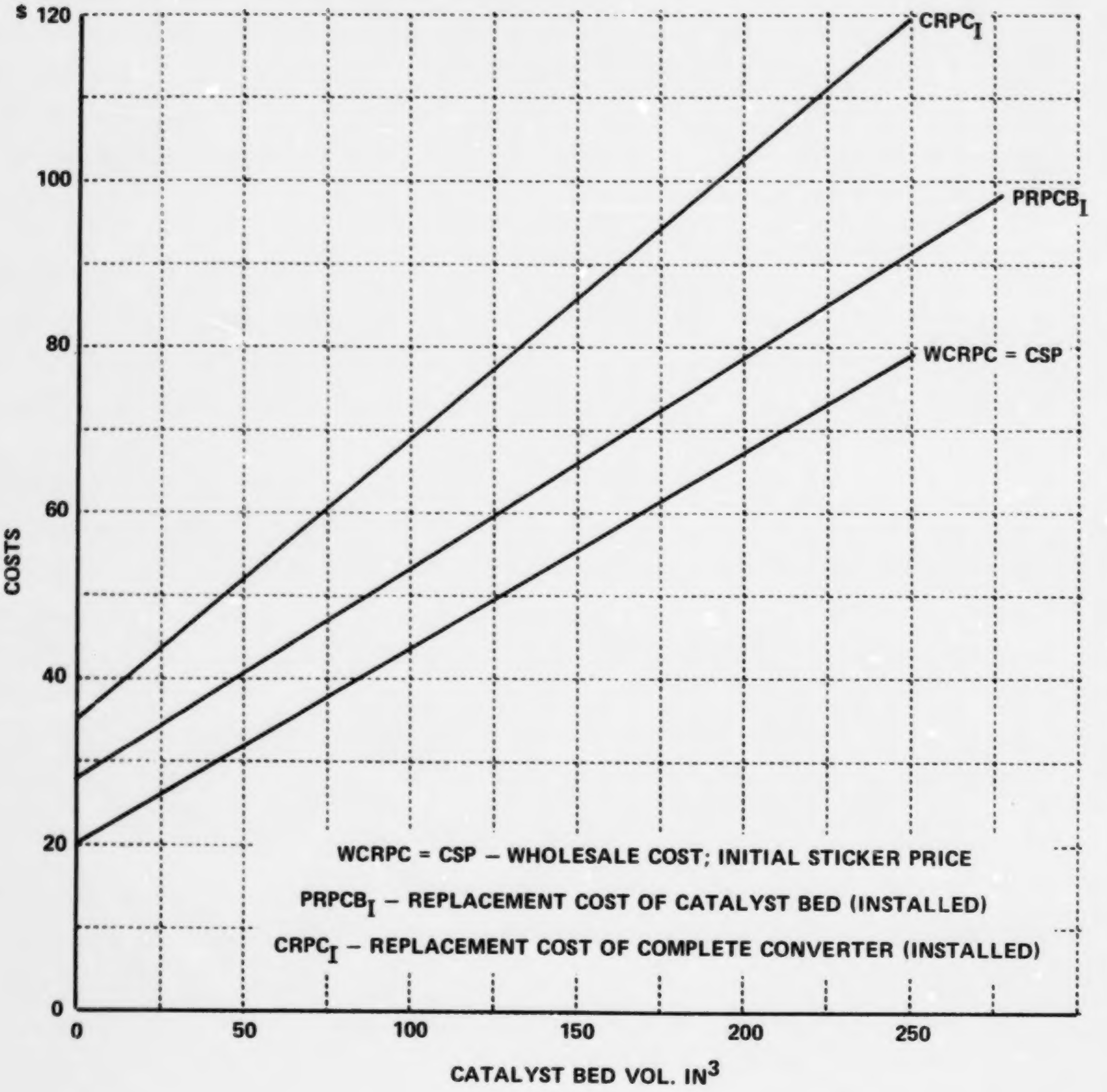

Figure 3.11 CATALYTIC CONVERTER COST

The UOP data provided the basis for estimating the replacement cost (installed) for catalytic converters, labeled $CRPC_I$ in Fig. 3.11. This cost was assumed to include 1/2 hour of labor at $12/hr. Thus, the replacement cost of the converter itself is $CRPC_I$-\$6. The wholesale cost (WCRPC) is estimated to be .7($CRPC_I$-\$6). Automobile manufacturers will undoubtedly pay less than WCRPC but will incur additional costs for receiving, installation and inspection. Thus, the initial sticker price CSP is assumed to be the same as the wholesale price.

It is estimated that 75% of the catalytic converter cost is for the catalyst bed and the remainder for the container. Thus, the cost to the customer for a replacement of the catalyst bed ($PRPCB_I$) is .75 ($CRPC_I$-\$6) + \$6 again assuming that this maintenance action involves one half hour of labor.

The three-way catalyst additionally includes an O_2 sensor with an initial cost of \$7. The sensor must be replaced every 25,000 miles at an estimated cost of \$13 which includes 1/2 hour of labor.

3.4.2.11 Lean and Rich Thermal Reactors (LTR & RTR)

Thermal reactors are estimated to cost 75% of the cost of comparably sized catalytic converters and are assumed to last the life of the vehicle.

A comparison of thermal reactor and catalytic converter sticker price costs derived herein with other published source costs is shown in Fig. 3.12. The other source data do not specify the specific engine size for which the devices are intended. The Calspan data is based on a 350 CID engine.

3.4.2.12 Oxidizing Catalyst Bypass

This device includes a thermocouple, a valve, a solenoid and some pipes. The estimated sticker prices of this device are L = \$5, A = \$10 and H = \$15.

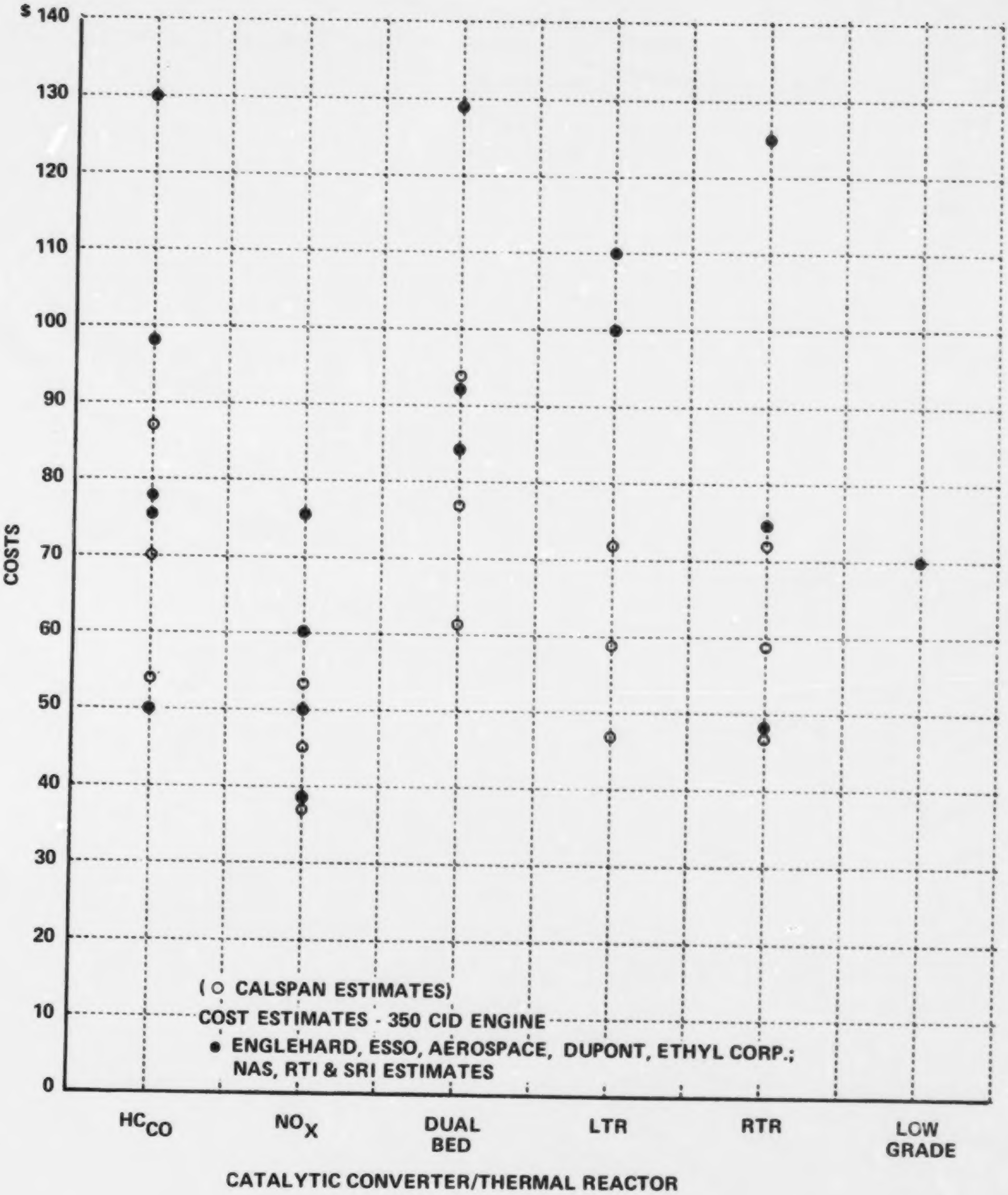

Figure 3.12 CATALYTIC CONVERTER & THERMAL REACTOR COST ESTIMATES– 350 CID ENGINE

The annual maintenance and inspection cost of this device based on 10,000 miles/year travel is $5.(4)

3.4.2.13 Evaporative Control

The evaporative control system consists of a domed tank vapor separator and carbon canister. The sticker price(11) is L = $13, A = $14 and H = $15. The carbon canister is estimated to require replacement after 25,000 miles at a cost of $12.50.

3.4.2.14 Emission Test

The emission test end-of-assembly line costs are assumed to be the same as the current California procedure (i.e. 2% CVS, 25% 7-Mode and 75% idle and functional checks). These costs(12) are included as L =$6, A =$7 and H =$8.

Recurring inspection and test costs are $3 per year.

3.4.3 Incremental Diesel Engine Costs

The use of diesel engines is considered to meet emission standards. The differences between the initial purchase price of the diesel vs. the baseline spark ignition engines represent a part of the cost of meeting the standard.

Initially, the cost of a baseline spark ignition engine must be determined. The difficulty here is to establish the cost for any one particular engine. Once this is accomplished, the determination of the costs of other engines is straightforward. This is because manufacturers quote price differentials for different sized engines. For example, the vehicle base price may include a small V8. Alternative prices are quoted for the same vehicle powered by a smaller I6 or larger V8 engines.

The cost differences associated with different engine sizes are independent of vehicle type. Discussions with truck dealers have shown that the cost difference between a small and large V8 is the same for a pick-up truck as for a Van; although the base sticker prices of the two vehicles may differ significantly.

An initial engine cost was derived as follows. We selected the smallest and next largest I6 engines which are installed in trucks in the 6-14,000 lbs. GVW category. The difference in costs between the engines was then divided by their difference in HP. This cost/HP was then used to compute the cost of the smaller I6.

The resultant costs for engines with displacements from 225-500 in^3 are presented in Figure 3.13.

The discussion following on diesel engines is based largely on discussions held with Mr. Neville Hartwell, Perkins Engine Co., on March 16, 1973.

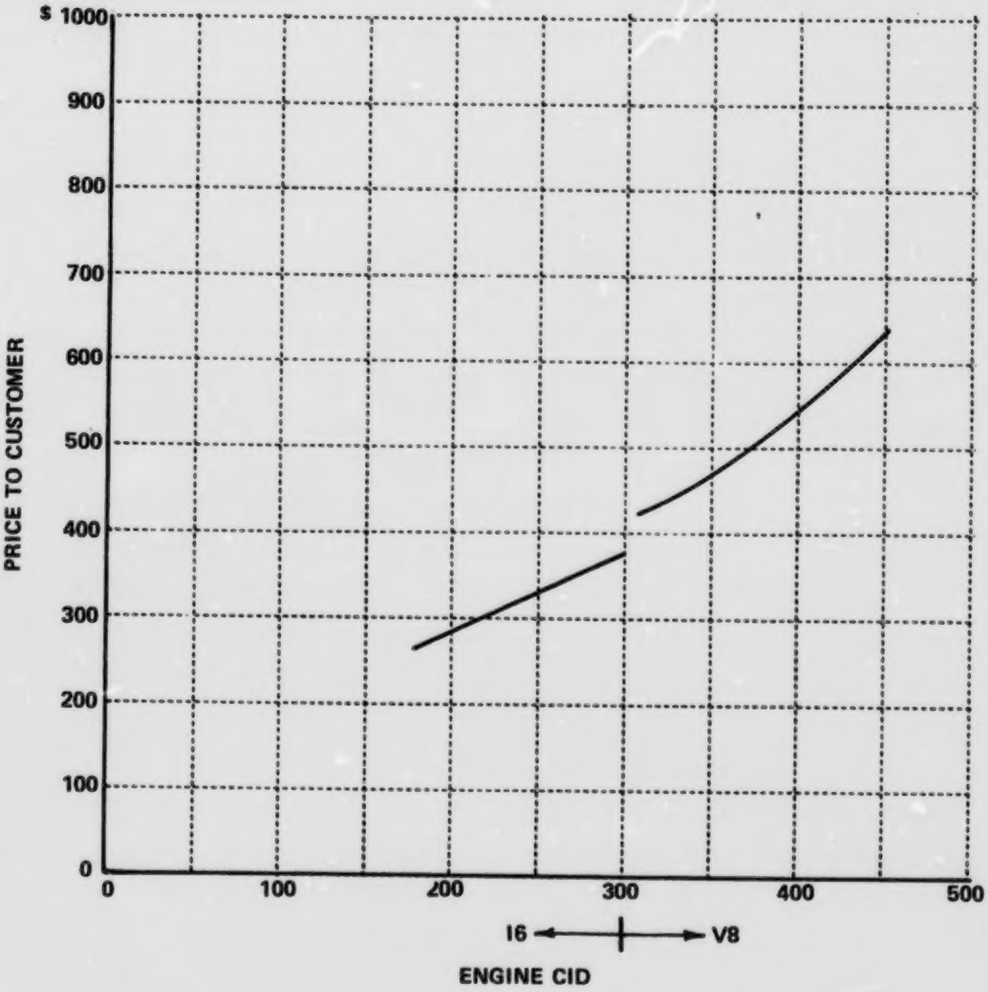

Figure 3.13 ESTIMATED COSTS OF CURRENT SPARK IGNITION ENGINES

Generally, current diesel engines are not designed for medium duty vehicles. New or modified designs of present engines with matched torque converters and automatic transmissions would have to be developed to meet the requirements of the medium duty vehicles. Lead times of 8-10 years would be needed to reach full production for a family of engines. This lead time could be reduced to about 5 years if the objective was to develop one engine which may have widespread applicability in medium duty vehicles.

These "new" diesel engines, if produced within present production capacities are estimated to cost twice as much as spark ignition engines with comparable CID's. Expanded production, i.e. equivalent to that of the current spark ignition engines, could result in a cost reduction of 25-30 percent.

Diesel engine costs, based on the premises of existing and expanded production facilities are shown in Figure 3.14.

Figure 3.15 shows the differences between the costs of spark ignition engines shown in Figure 3.13 and the high and low diesel engine costs presented in Figure 3.14. The middle line in Fig. 3.15 is based on the midpoints of the high and low diesel engine costs in Figure 3.14. For example, the incremental, anticipated sticker price for a 350 CID diesel engine is $355.

3.4.3.1 Other Diesel Engine Associated Costs

The only emission control device considered with the diesel engine is EGR. Its cost is assumed to be the same as that for the spark ignition engines, i.e. L = $20, A = $30, and H = $40. Additionally, a $100 incremental cost is charged to all diesel powered vehicles to cover structural changes and improved brakes which may be required because of the higher weight of diesel engines. Finally, the cost of power steering, $125, is added to all diesel powered vehicles with engine displacements of less than

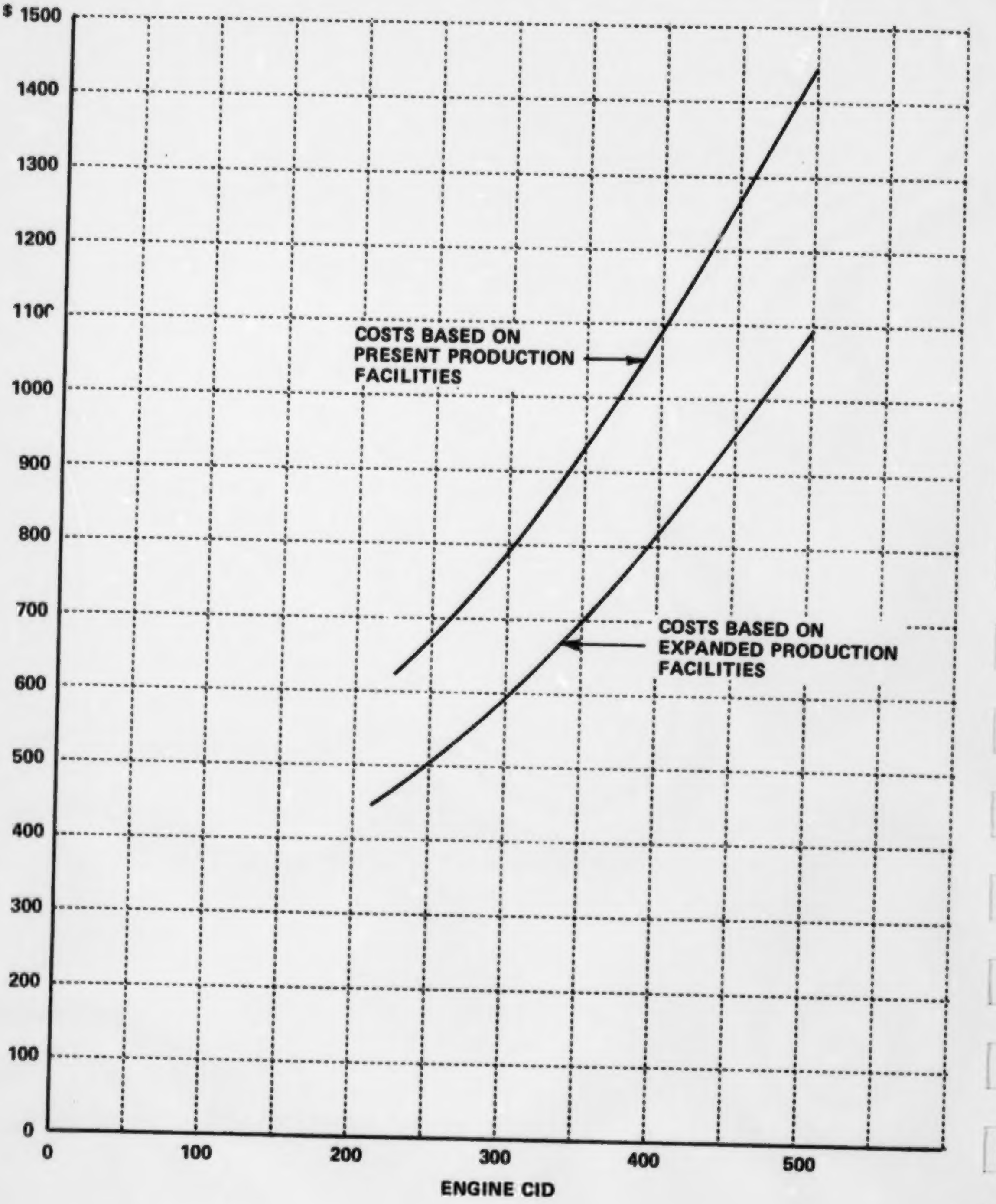

Figure 3.14 ESTIMATED COSTS OF DIESEL ENGINES

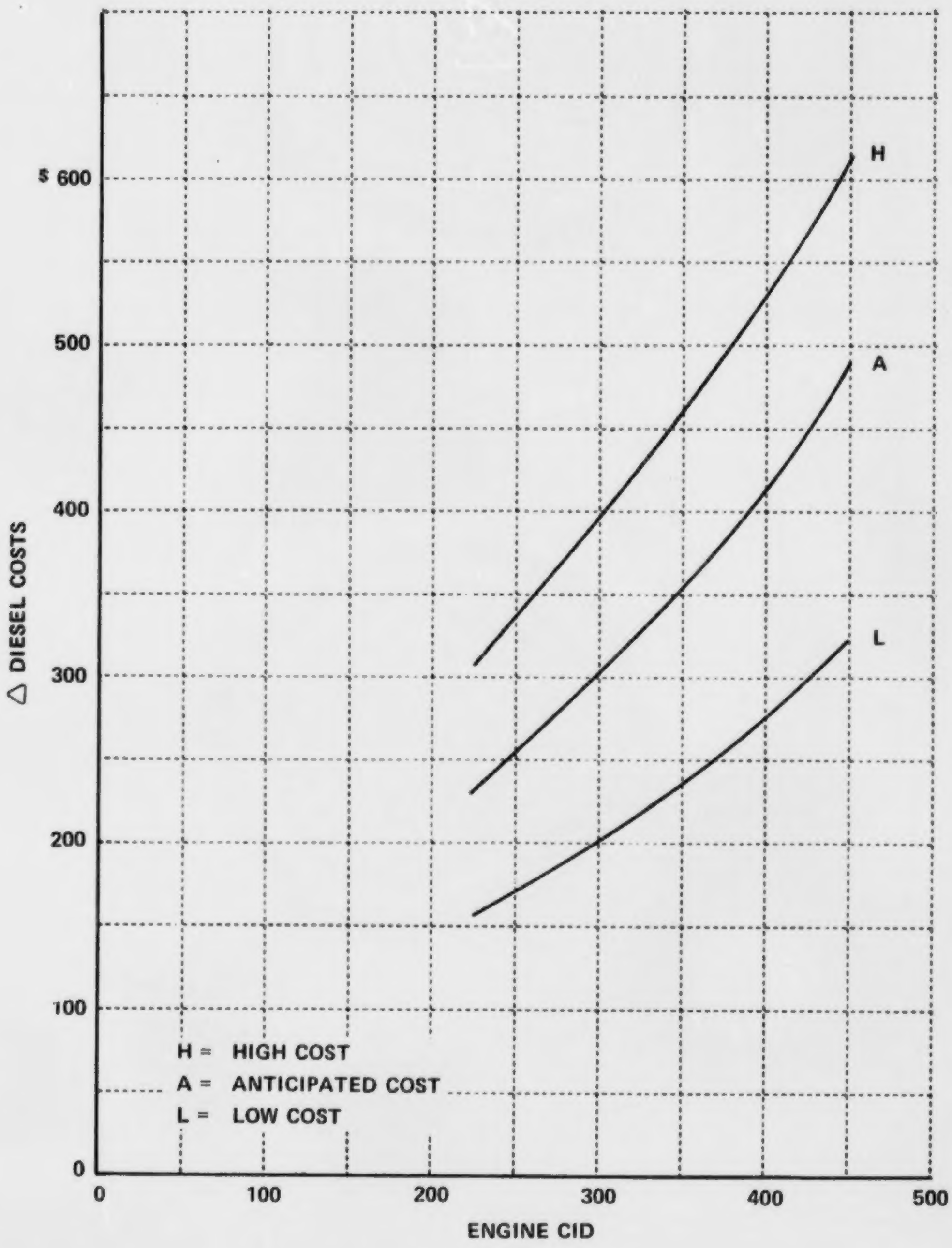

Figure 3.15 INCREMENTAL DIESEL ENGINE COSTS

350 cu. in. It is assumed that all vehicles, gasoline or diesel, equipped with 350 CID or larger engines, normally would be delivered with power steering.

Historically, diesel engines have exhibited lower maintenance costs than comparable gasoline engines. The new type diesel engines we are considering represent an unknown item. Consequently, we assign no maintenance cost savings to the diesel engine compared to the baseline spark ignition engine. This represents a conservative approach biased in favor of the spark ignition engine. The diesel engine, as a new concept, however, is the challenger in this case. Its credibility as a substitute engine will be enhanced if it can be proved to be more cost-effective despite this bias.

The only incremental maintenance cost shown for the diesel engine is that associated with its EGR. This cost is the same as the EGR maintenance cost described in Section 3.4.2.7.

3.5 Emission Control System Costs

Eight emission control systems for use with spark ignition engines are developed and described in the Part A Technical Analysis. The costs of these systems and the incremental costs incurred with diesel engines are presented in this section.

Separate costs are first shown for each of the three major cost categories considered.

1. Initial or sticker prices to customers
2. Incremental maintenance costs
3. Incremental operating costs.

The last category reflects changes in fuel consumption resulting from the implementation of the systems. The costs are based on the cost factors described in the preceding Section 3.4. The total costs are the sum of the three costs based on 50,000 miles or 5 years of vehicle usage.*

Costs are shown for three representative engine sizes employed in medium duty vehicles. They are: I6-300 CID, V8-350 CID and V8-454 CID.

3.5.1 Sticker Prices of Emission Control Systems and Diesel Engines

Estimated sticker price increases for the eight emission control systems are shown in Table 3.6, Low (L), projected anticipated (A) and high (H) costs are indicated for each system. The initial sticker prices range from about $100 to $400; the higher cost systems are those which include catalytic converters.

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*Certification costs are not included. These costs are highly uncertain at this time and may vary considerably between manufacturers. This problem is addressed in Section 3.7.1.

TABLE 3.6

STICKER PRICES OF EMISSION CONTROL SYSTEMS

SYS. NO.		SYSTEM	I6-300	V8-350	V8-454
	L	EI+FC+AI+EGR+EC+ET	$ 95	$ 97	$ 97
1	A		112	114	114
	H		129	131	131
	L	EI+AI+EGR+IC+QHI+EC+ET	100	102	102
2	A		122	124	124
	H		144	146	146
	L	EI+AI+EGR+IC+QHI+OCBP+OC+EC+ET	154	161	171
3	A		195	204	219
	H		237	253	268
	L	EI+EGR+IC+QHI+OC+RC+OCBP+AI/CAI+EC+ET	204	236	255
4	A		259	295	325
	H		306	356	396
	L	EI+EGR+OC/RC+EFIC+EC+ET	185	190	200
5	A		241	248	263
	H		298	307	327
	L	EI+EGR+IC+QHI+LTR+EC+ET	106	111	120
6	A		139	145	159
	H		172	180	197
	L	EI+FC+AI+EGR+RTR+EC+ET	137	144	153
7	A		165	173	186
	H		193	203	220
	L	EI+AI+EGR+QHI+FIC+EC+ET	110	112	112
8	A		142	144	144
	H		174	176	176

Control systems Nos. 1, 2 and 8 are insensitive to engine displacement. In the remaining systems, the relatively large variations in costs both as a function of engine displacement and between low and high costs are due to the assumptions made concerning the sizes of the catalytic converters and thermal reactors. The values employed are shown below:

OR, RC & OC/RC	L = 40% CID	A = 60% CID	H = 80% CID
LTR & RTR	L = 50% CID	A = 70% CID	H = 90% CID

System Nos. 3 and 5 use one OC or OC/RC, respectively, for both the I6 and V8 engine configurations. System No. 4 includes one OC and one RC for the I6 engine. The V8 engines have one OC and 2 RC's, one in each bank.

The incremental sticker prices incurred with diesel engines are shown in Table 3.7. The major portion of the costs consists of the initial higher price of diesel engines compared to current spark ignition engines. The apparent cost discrepancy between the I6-300 and V8 engines is due to the fact that power steering is included as mandatory with the diesel I6 whereas the larger gasoline engines are assumed to be already provided with power steering.

3.5.2 Maintenance Costs of Emission Control Systems and Diesel Engines

These costs are shown in Tables 3.8 and 3.9. They are incremental costs computed for 50,000 miles or five years of vehicle operation.

The 5 year incremental maintenance costs are relatively low for the systems which do not use catalytic converters. Two types of maintenance costs are shown for the three catalytic converter systems, Nos. 3, 4 and 5. The first cost includes one replacement of the entire catalytic converter(s); the second replacement of the catalyst bed(s) only. Either choice has a significant impact on maintenance costs involving substantial costs to the customer.

TABLE 3.7

STICKER PRICES OF DIESEL ENGINE SYSTEMS

SYSTEM		ENGINE SIZE $300^{(1)}$ in^3	 350 in^3	 454 in^3
△DIESEL ENGINE COST+ET(2)+MISC.(3)	L	$ 431	$ 341	$ 436
	A	532	462	602
	H	633	573	733
△DIESEL ENGINE COST+EGR+ET+MISC.	L	451	361	456
	A	562	492	632
	H	673	613	773

1. 300 in^3 Engine included Power Steering Cost ($125)
2. Emission Test (ET) cost is (L)$6, (A)$7, (H)$8
3. MISC includes $100 cost increment for added weight and design

TABLE 3.8

INCREMENTAL MAINTENANCE COSTS (50,000 MI.)

SYS. NO.		SYSTEM	I6-300	V8-350	V8-454
1	L	EI+FC+AI+EGR+ EC+ET	$ 9	$ 10	$ 10
	A		9	10	10
	H		9	10	10
2	L	EI+AI+EGR+IC+ QHI+EC+ET	24	25	25
	A		24	25	25
	H		24	25	25
3	L	EI+AI+EGR+IC+ QHI+OC+EC+ET +OCBP	124/106.5	132.5/112.5	147.5/122.5
	A		146.5/121.5	157.5/130	177.5/145.5
	H		166.5/136	180/147.5	207.5/170
4	L	EI+EGR+IC+QHI+ OC+RC+AI/CAI+ EC+ET+OCBP	199/164	250/202.5	280/225
	A		244/194	300/237.5	340/270.5
	H		274/224	345/272.5	400/317.5
5	L	EI+EGR+OC/RC+ EFIC+EC+ET	111.5/94	123/103	138/113
	A		134/109	148/120.5	168/135.5
	H		154/124	170.5/138	198/160.5
6	L	EI+EGR+IC+QHI LTR+EC+ET	15	15	15
	A		15	15	15
	H		15	15	15
7	L	EI+FC+AI+EGR +RTR+EC+ET	9	10	10
	A		9	10	10
	H		9	10	10
8	L	EI+AI+EGR+QHI EC+ET+FIC	54	55	55
	A		54	55	55

Note: With 1 replacement of converter(s)/with 1 replacement of converter element(s).

TABLE 3.9

DIESEL MAINT. COSTS (50,000 MI.)

	$ LOW	$ ANTICIPATED	$ HIGH
DIESEL			
ET	15	15	15
TOTAL	15	15	15
DIESEL W EGR			
EGR	20	20	20
ET	15	15	15
TOTAL	35	35	35

The incremental diesel engine maintenance costs are relatively small. In fact, they will be probably considerably lower than indicated. Present experience shows that diesel engines are inherently more reliable and require less maintenance than comparable gasoline engines. This factor is not considered in the determination of the diesel engine maintenance costs.

3.5.3 Incremental Fuel Costs of Emission Control Systems and Diesel Engines

Incremental fuel costs incurred due to emission control systems are listed in Table 3.10. Baseline fuel consumptions are based on representative inertial weights of vehicles in which the various size engines may be installed. Fuel savings resulting from the use of diesel engines are contained in Table 3.11. All fuels are estimated to cost $0.45 per gallon. Inquiries addressed to local dealers indicated no significant differences in retail prices between gasoline and diesel fuels.

3.5.4 Total Costs

The total system costs shown in Tables 3.12 and 3.13 are the sum of:

STICKER PRICE + INCREMENTAL MAINT. COST + INCREMENTAL FUEL COST

The total costs are for 50,000 miles of vehicle operation. They include one replacement of catalytic converters for those systems which employ these devices.

A range of inertial weights is included here to correspond to the engine sizes considered. Note that different inertial weights are used in the analysis conducted with the AMTEC model.

TABLE 3.10

INCREMENTAL FUEL COSTS (50,000 MI.)

				ENGINES		
			%	I6-300	V8-350	V8-454
TESTED INERTIAL WEIGHT				6000 lbs.	9000 lbs.	11,000 lbs.
BASELINE FUEL USAGE (MPG)			0	11.5	7.3	5.5
		L	-4	$ 80	$ 123	$ 168
SYSTEM NUMBER	1	A	-7	147	225	307
		H	-10	217	333	454
		L	-3	59	90	123
	2	A	-5	102	156	213
		H	-7	147	225	307
		L	-10	217	333	454
	3	A	-12	266	408	556
		H	-14	317	486	663
		L	-10	217	333	454
	4	A	-12	266	408	556
		H	-14	317	486	663
		L	-1	20	30	41
	5	A	-3	59	90	123
		H	-5	102	156	213
		L	-6	123	189	258
	6	A	-8	168	258	352
		H	-10	217	333	454
		L	-20	489	750	1023
	7	A	-25	651	999	1362
		H	-30	837	1284	1751
		L	-1	20	30	41
	8	A	-3	59	90	123
		H	-5	102	156	213

TABLE 3.11

DIESEL OPERATING COST - (50,000 MI.)

	$300\ in^3$	$350\ in^3$	$454\ in^3$
DIESEL WITHOUT EGR			
BASELINE FUEL USAGE (MPG)	17.3	11	8.3
DIESEL	$-656	$-1037	$-1380
DIESEL WITH EGR			
BASELINE FUEL USAGE (MPG)	17	10.7	8.1
DIESEL	$-634	$-979	$-1313

Note:

- = Savings

TABLE 3.12

TOTAL SYSTEM COST - (50,000 MI.)

				ENGINES	
			I6-300	V8-350	V8-454
INERTIAL WEIGHT			6000 LBS.	9000 LBS.	11,000 LBS.
SYSTEM NUMBER	1	L	$ 184	$ 230	$ 275
		A	268	349	431
		H	355	474	595
	2	L	183	217	250
		A	248	305	362
		H	315	396	478
	3	L	495/478	627/607	773/748
		A	608/583	770/742	953/921
		H	721/691	919/887	1139/1101
	4	L	620/585	819/772	989/934
		A	769/719	1003/941	1221/1152
		H	897/847	1187/1115	1459/1377
	5	L	317/229	343/323	379/354
		A	434/409	486/459	554/522
		H	554/524	634/601	738/701
	6	L	244	315	393
		A	322	418	525
		H	404	528	666
	7	L	635	904	1186
		A	825	1182	1558
		H	1039	1497	1981
	8	L	184	197	208
		A	255	289	322
		H	330	387	444

Note: With 1 replacement of converter(s)/with 1 replacement of converter element(s).

TABLE 3.13

DIESEL ENGINE TOTAL SYSTEM COSTS

(50,000 MI.)

		ENGINE SIZES		
		300 in^3	350 in^3	451 in^3
	L	$ - 210	$-681	$-929
Diesel	A	- 109	-560	-763
	H	- 8	-449	-632
	L	- 148	-583	-822
Diesel with EGR	A	- 37	-452	-646
	H	74	-331	-505

Note:

- = Savings

3.6 Emission Control System Lead Times

Estimated lead times for the eight emission control systems are shown in Figure 3.16. The lead time categories considered are:

1. Initial design
2. Prototype development
3. Prototype test and evaluation
4. Certification
5. Design review
6. Production facility planning, construction and tooling
7. Preproduction
8. Initial production

The presented lead times are predicated on a sequential progression of activities culminating in the initial production of a system. For example, it is assumed that work on new production facilities (where required) is not initiated until after system certification. An earlier decision to proceed together with the attendent commitment of necessary funds could result in appreciably reducing some of the indicated lead times. This is particularly true with regard to the systems which include catalytic converters on thermal reactors.

The eight emission control systems are presently in varying stages of development. For example, development of system No. 1 is essentially complete. In contrast, the advanced carburetion system employed in System No. 8 is best designated as a concept at this time.

Most systems require the development of more than one new device. It is assumed that parallel efforts are conducted in these instances and the time periods shown reflect that device deemed to have the longest lead time.

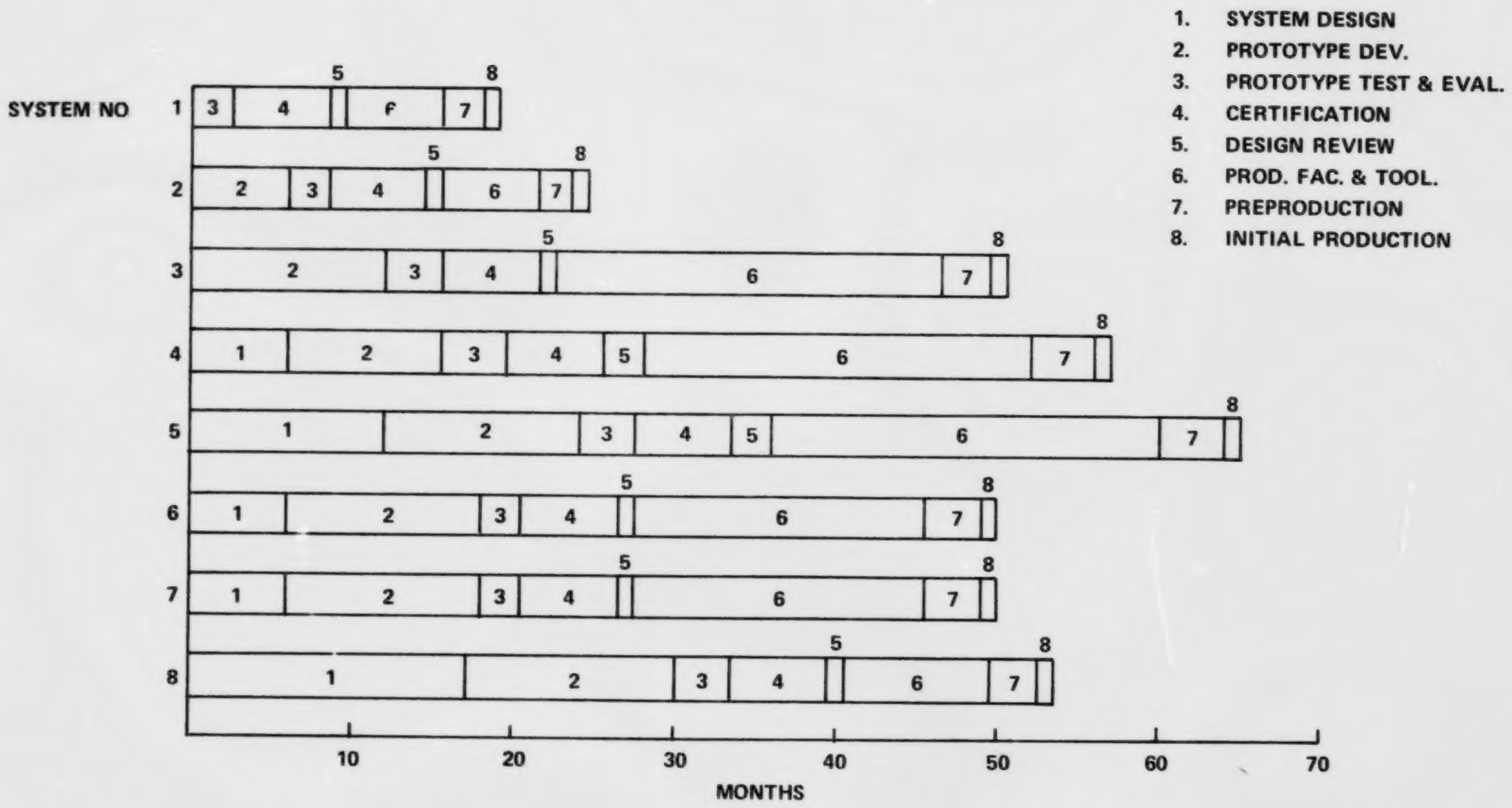

Figure 3.16 ESTIMATED SYSTEM LEAD TIMES

The devices which are believed to require the longest lead times are the catalytic converters -- approximately 24 months. A detailed discussion of the derivation of this lead time is contained in Appendix B.

Generally 2 1/2 to 4 months are allocated for prototype test and evaluation, 6 months for certification and 1-2 months for design review at which time the decision to proceed with production is made.

Lead time category No. 6, concerned with production facilities and tooling varies considerably between the systems. The required activities may vary here from minor to major production line changes to the construction of entirely new facilities. The time allocated for these activities vary from 6 months to 2 years.

Three months are allotted for preproduction and one additional month reach initial mass production.

Systems Nos. 1 and 2 could become available within 2 years. For example, General Motors and Chrysler Corporation indicate lead times of 25-28 months for carburetors similar to the improved carburetors included in Systems Nos. 1 and 2.(15) Systems employing catalytic converters (3, 4 and 5) are shown to have lead times of 4-6 years; thermal reactor systems about 4 years.

Discussions with Perkins Engine Co. personnel indicated that large-scale production of a family of diesel engines could not be achieved before 1980-1982. Production of one engine with wide applicability, such as a 350 CID diesel engine, given the necessary priority, may be possible by 1978-1979.

3.7 System Comparison

Table 3.14 lists the emission control systems and their estimated effectiveness (i.e. emission reduction) ranked in the order of ascending costs. The comparison is for a V8-350 CID spark ignition engine.

Based on effectiveness, cost and lead times, systems Nos. 1, 4 and 7 do not appear to offer any benefits which cannot be achieved with other systems more efficiently and economically. System No. 2 is cheaper and more effective than No. 1 and becomes available at approximately the same time. System No. 5 matches the effectiveness of No. 4 at less than one half its cost. The difference in lead times between the systems is less than 1 year. System No. 7 is characterized by high costs due mainly to the large fuel penalty associated with it. System No. 5 can provide approximately the same benefits at a much lower cost, albeit one year later.

Comparable data for the two diesel engine configurations, system No. ID with out EGR and No. 2D with EGR, are presented in Table 3.15. Both systems offer more than 90% reductions in HC and CO, but only 42-67 reductions of baseline NO_x emissions. The total costs of both diesel engine systems are significantly lower than that of the baseline engine and provide significant fuel savings. It must be recognized, however, that large-scale production of a family of diesel engines for medium duty vehicles is 8-10 years in the future.

As described in the introductory section 3.1, the emission control systems considered offer basically three choices or routes for the reduction of emissions. These are designated as: 1. improved carburetion, 2. catalytic converters and 3. thermal reactors. This represents somewhat of an oversimplification since the improved carburetion (IC) of system No. 2 appears in systems No. 3 and 6 as well. The latter two systems also include an oxidizing catalytic converter and a thermal reactor, respectively.

TABLE 3.14

EMISSION CONTROL SYSTEM COMPARISON: V8-350 ENGINE

(9000 lbs. inertial weight)

SYS. NO.	AVERAGE EMISSION REDUCTION			TOTAL COSTS (50,000 MI.)			Δ FUEL USED (GAL.)	
	% HC	% CO	% NO_X	RANGE L	RANGE H	ANTICIPATED A	RANGE L-H	ANTICIPATED A
8	60	70	65	197	387	289	67-347	200
2	35	45	40	217	396	305	200-500	347
1	-30	5	35	230	474	349	273-740	500
6	50	65	62	315	528	418	420-740	573
5	82	85	90	323 343	601[1] 634[2]	459[1] 486[2]	67-347	200
3	82	85	40	607 627	887[1] 919[2]	742[1] 770[2]	740-1080	907
4	82	85	90	772 819	1115[1] 1187[2]	941[1] 1003[2]	740-1080	907
7	92	65	83	904	1497	1182	1667-2853	2220

[1] with one (1) replacement of catalyst element

[2] with one (1) replacement of complete converter

TABLE 3.15

EMISSION CONTROL SYSTEM COMPARISON - DIESEL 350 CID

(9000 lbs. inertial weight)

SYS. NO.	EMISSION REDUCTION % HC	% CO	% NO_X	TOTAL COST (50,000 mi)	FUEL SAVINGS GALLONS
1D	96	95	42	\$-560	2304
2D	96	95	67	\$-452	2176

Note:

- = Savings

Emission control through improved carburetion can be achieved largely using existing production facilities. The other two choices will require extensive capital expenditures for new production facilities for the manufacture of catalytic converters and thermal reactors.

The three approaches are outlined in Table 3.16. All are initiated with the introduction of system No. 2 which can be made available within 2 years. The improved carburetion and thermal reactor approaches result in approximately equal effectiveness. The use of catalytic converters potentially offer the greatest reduction of pollutant emissions. The most advanced catalytic converter system (No. 5) emits about one half of the HC and CO and one third of NO_x of the best postulated advanced carburetion system (No. 8).

Tables 3.17, 3.18, 3.19 and 3.20 show the effectiveness and costs of the various approaches considered. The data are presented for a 350 CID engine for each of the 4 major vehicle categories. Effectiveness is expressed in terms of grams/mile of residual emissions. The costs are for 50,000 miles of operation and include the initial sticker price, incremental maintenance and fuel costs.

The diesel engine appears to offer the best long term solution of the emission problem. It provides the best control of HC and CO emissions of the systems considered. Its control of NO_x emissions is roughly comparable to what can be achieved with the best "improved carburetion" systems but not as good as the most advanced catalytic converter system No. 5.

Diesel engines provide economy in operations far superior to any of the other alternatives considered. Their cost advantage derives from their significantly lower fuel consumption which more than off-sets the higher initial sticker prices of diesel-powered vehicles.

The various emission control approaches described earlier were examined with the AMTEC model. The cases considered are listed in Table 3.21.

TABLE 3.16

System Comparison V8 - 350 Engine

Lead Time (Years)	Improved Carburetion Sys.	% Reduction			Catalytic Converter Sys.	% Reduction			Thermal Reactor Sys.	% Reduction		
		HC	CO	NO_x		HC	CO	NO_x		HC	CO	NO_x
1	(2)	35	45	40	(2)	35	45	40	(2)	35	45	40
2												
3												
4	(8)	60	70	65	(3)	82	85	40	(6)	50	65	62
5					(5)	82	84	90				
6												

TABLE 3.17

IMPROVED CARBURETION EFFECTIVENESS AND COSTS - 350 CID ENGINE

(50,000 MILES)

VEHICLE TYPE	INERTIAL WT. LBS.	RESIDUAL EMISSIONS GM/MI HC	CO	NO_X	TOTAL COSTS (ANTICIPATED)
System No. 2					
Truck	6,000	3.5	33.0	4.6	$ 266
Truck	10,000	4.9	49.5	7.1	323
Motor Home	8,000	5.3	56.7	7.2	297
Motor Home	12,000	12.5	110.0	16.2	354
System No. 8					
Truck	6,000	2.1	18.0	2.7	268
Truck	10,000	3.0	27.0	4.1	301
Motor Home	8,000	3.2	30.9	4.2	286
Motor Home	12,000	7.7	60.0	9.5	320

Note:

Trucks are assumed to be lightly loaded. The inertial weights of the motor homes are selected at the midpoints of the 6-10,000 and 10-14,000 lbs. GVW categories.

TABLE 3.18

THERMAL REACTOR EFFECTIVENESS AND COSTS - 350 CID ENGINE

(50,000 MILES)

VEHICLE TYPE	INERTIAL WT. LBS.	RESIDUAL EMISSIONS GM/MI HC	CO	NO_X	TOTAL COSTS (ANTICIPATED)
System No. 2					
Truck	6,000	3.5	33.0	4.6	$ 266
Truck	10,000	4.9	49.5	7.1	323
Motor Home	8,000	5.3	56.7	7.2	297
Motor Home	12,000	12.5	110.0	16.2	354
System No. 6					
Truck	6,000	2.7	21.0	2.9	353
Truck	10,000	3.8	31.5	4.5	447
Motor Home	8,000	4.1	36.1	4.6	404
Motor Home	12,000	9.7	70.0	10.3	500

Note:

Ibid Table 3.17.

TABLE 3.19

CATALYTIC CONVERTER EFFECTIVENESS AND COSTS - 350 CID ENGINE

(50,000 MILES)

VEHICLE TYPE	INERTIAL WT. LBS.	RESIDUAL EMISSIONS GM/MI HC	CO	NO_X	TOTAL COSTS (ANTICIPATED)
System No. 2					
Truck	6,000	3.5	33.0	4.6	$ 266
Truck	10,000	4.9	49.5	7.1	323
Motor Home	8,000	5.3	56.7	7.2	297
Motor Home	12,000	12.5	110.0	16.2	354
System No. 3					
Truck	6,000	1.0	9.0	4.6	582/610
Truck	10,000	1.4	13.5	7.1	701/729
Motor Home	8,000	1.5	15.5	7.2	646/674
Motor Home	12,000	3.5	30.0	16.2	769/797
System No. 5					
Truck	6,000	1.0	9.6	.8	438/465
Truck	10,000	1.4	14.4	1.2	471/498
Motor Home	8,000	1.5	16.5	1.2	456/483
Motor Home	12,000	3.5	32.0	2.7	490/517

Notes: For systems Nos. 3 and 5: With one replacement of the catalyst element/
With one replacement of catalytic converter.

Ibid Table 3.17

TABLE 3.20

DIESEL ENGINE EFFECTIVENESS AND COSTS - 350 CID ENGINE

(50,000 MI.)

	INERTIAL WT. LBS.	RESIDUAL EMISSIONS GM/MI HC	CO	NOX	TOTAL COSTS (ANTICIPATED)
Diesel #1					
Truck	6,000	.2	2.7	4.4	$-290
Truck	10,000	.3	4.1	6.7	-669
Motor Home	8,000	.3	4.4	6.7	-507
Motor Home	12,000	.7	8.3	15.3	-908
Diesel #2					
Truck	6,000	.2	2.7	2.5	-211
Truck	10,000	.3	4.1	3.8	-576
Motor Home	8,000	.3	4.4	3.8	-411
Motor Home	12,000	.7	8.3	8.7	-800

Note:

Ibid Table 3.17.

TABLE 3.21

ALTERNATIVE EMISSION CONTROL APPROACHES

Run No.	System No.	Year Introduced
I	2	1975
II	2	1975
	8	1978
III	2	1975
	6	1977
IV	2	1975
	3	1977
	5	1978
V	2	1975
	8	1978
	Diesel + EGR	1978
VI	2	1975
	3	1977
	5	1978
	Diesel + EGR	1978

Phase-in of Diesel Engines (% of Annual Sales)

Trucks 6000 lbs. GVW: 5%-1978, 10%-1979, 25%-1980-1989

Trucks 10,000 lbs. GVW: 10%-1978, 20%-1979, 35%-1980, 50%-1981, 65%-1981-1989

Motor Homes 8000 lbs. GVW: 5%-1978, 10%-1979, 25%-1980, 50%-1981-1989

Motor Homes 12,000 lbs. GVW: 10%-1978, 20%-1979, 35%-1980, 50%-1981, 65%-1982-1989

The results are presented in Table 3.22. The data shown for each approach include:

1. Emission reductions in specified years as a percent of baseline emissions
2. Fuel penalty/(savings) expressed as a percent of the baseline fuel consumption
3. Total annual low and high costs; and
4. Anticipated costs over the 15 year period.

Baseline emissions are the quantities of pollutants which would be emitted in the absence of control systems. The greater effectiveness of the systems over the years result from the fact that vehicles equipped with control devices comprise an increasing segment of the total medium duty vehicle population. The 1989 emission reduction percentages are very close to the greatest reductions that can be achieved with the systems.

The annual costs are successively higher for each of the four years considered for the approaches which utilize gasoline engines equipped with emission control systems. Approaches which include diesel engines show declining costs in the years following the introduction of these engines. The declining costs are due to the considerably greater fuel economy of these engines.

The annual costs are close to their levelling off points by 1989 for the specified mix of vehicles. This is indicated by the fact that emission reductions are almost equal to the greatest reduction possible with the control systems.

The approaches which use only gasoline engines with emission control systems result in fuel penalties ranging from 3-8 percent. The inclusion of diesel engines result in fuel savings of 6-7 percent. These percentages are relative to the fuel consumption which would have occurred if the vehicle population had been equipped with the baseline gasoline engine without emission control systems throughout the period.

TABLE 3.22

Effectiveness and Annual Costs of Emission Control Approaches

	1975	1980	1985	1989	Total Anticipated Costs, 1975-1989 \$ Billions
Sys. No. 2					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	23/27/27	31/40/36	34/44/39	
Fuel Penalty/(Savings) (%)	1	3	5	5	
Costs Low - High (\$M)	88-123	189-253	290-384	363/478	3.991
Sys. Nos. 2 & 8					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	30/36/36	50/59/55	57/67/62	
Fuel Penalty/(Savings) (%)	1	3	3	3	
Costs Low - High (\$M)	88-123	181-259	249-352	297-418	3.683
Sys. Nos. 2 & 6					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	28/36/38	43/56/55	48/63/61	
Fuel Penalty/(Savings) (%)	1	5	7	8	
Costs Low - High (\$M)	88-123	238-337	394-541	506-689	5.338
Sys. Nos. 2, 3, & 5					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	42/45/40	69/72/71	79/72/83	
Fuel Penalty/(Savings) (%)	1	4	4	3	
Costs Low - High (\$M)	88-123	286-423	359-530	409-605	5.417
Sys. Nos. 2 & 8, with Diesel + EGR					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	33/38/36	64/69/56	77/81/64	
Fuel Penalty/(Savings) (%)	1	0	(4)	(7)	
Costs Low - High (\$M)	88-123	184-294	59-161	(49)-39	2.042
Sys. Nos. 2, 3 & 5 with Diesel + EGR					
Emission Reductions $HC/CO/NO_x$ (%)	4/5/11	43/46/38	75/76/62	86/88/72	
Fuel Penalty/(Savings) (%)	1	2	(4)	(6)	
Costs Low - High (\$M)	88-123	269-425	141-291	32-172	3.400

Note: ( ) denote savings

Total costs for systems Nos. 3 and 5 include replacement of the entire catalytic converter(s) every 25,000 miles.

Percent emission reductions are relative to 1972 base line engine.

The total anticipated incremental costs incurred over the 15 year period by implementing the alternative approaches are shown in the last column. These costs range from about $2 billion to $5.4 billion.

The "best" approach depends largely on the extent to which the pollutant emissions must be reduced, particularly NO_X. Systems Nos. 2 and 8 provide about a 60 percent reduction of emissions by 1989 with a fuel penalty of about 3 percent. Further reductions, without introducing diesel engines, requires the use of catalytic converters. The cost of this approach, system Nos. 2, 3 and 5, increases the total cost by about 50 percent - $3.7 vs. 5.4 billion.

The introduction of diesel engines equipped with EGR, in addition to equipping the gasoline engines with system Nos. 2 and 8 offers about an 80 percent reduction of HC and CO and a 64 percent reduction of NO_X by 1989. This reduction is achieved at the relatively low cost of $2 billion. Concurrently annual fuel savings of about 7 percent are obtained.

Combining catalytic converter systems on gasoline engines with diesel-powered vehicles provides slightly greater emission reductions. The cost of this approach is $3.4 billion.

We conclude from the above analysis that the introduction of diesel engines together with improved carburetion on gasoline engines provides the most cost-effective approach. It is noted that this approach following its implementation results in no additional costs above the baseline engines. As shown in Table 3.22, the annual cost of this approach is about $0 by 1989. Greater proportions of diesel engines in the vehicle mix than assumed here would result in negative costs, i.e. savings.

3.7.1 Certification Costs

It is not possible to specify a certification fleet and estimate certification costs without precise specification and knowledge of certification standards, engine-emission control system combinations as well as other variables which may impact on the pollutant emissions. In the absence of such data, a crude estimate of certification fleet costs is made based on LDV experience. A set of conditions, as they may apply to medium duty vehicles, is then postulated and certification fleet requirements and costs established.

General Motor's emission test fleet for light duty vehicles in 1972 included 19 durability and 72 emission test vehicles.(14) Total sales of such vehicles were about 5.5 million.(14) Information provided by EPA(12) reflecting primarily G.M. experience indicated a manufacturers' certification fleet cost of $3.41 per vehicle produced. This yields a total cost of $18.8 million and a cost of about $.2 million per test vehicle.

There is a high degree of uncertainty associated with these costs. Initially, the costs of durability and emission data vehicles may be drastically different with the former displaying higher costs. Additionally, the lack of data did not permit addressing cost differentials based on manufacturer's size and available facilities.

The total number of vehicles produced in the 6-14,000 lbs. GVW range is only about 5 percent of the number of light duty vehicles. The costs of certification fleets can, therefore, become a significant sticker price cost factor, particularly for the smaller manufacturers and for vehicle types which are produced in relatively small quantities.

3.7.1.1 Example

The 6,000-14,000 lbs. GVW vehicles are divided into two weight classes: 6,000-10,000 lbs. GVW and 10,000-14,000 lbs. GVW. There are five engine families within each weight class. LDV certification procedures are assumed applicable to the medium duty vehicles.

The resultant categorizations are shown in Tables 3.23 and 3.24. The percent of sales of engines with given CID's are based on manufacturers' 1973 sales projections.

One control system, designated A, is used on all vehicles in the 6-10,000 lbs. GVW class. Two emission control systems, designated as A and B, are employed on the vehicles in the 10-14,000 lbs. GVW range.

The resultant numbers of required durability and emission test fleet vehicles are shown at the bottom of Tables 3.23 and 3.24. A maximum of four "B" vehicles are permitted per engine family. "C" vehicles are selected only when an engine-emission system combination is not represented by an "A" or "B" vehicle.

The total postulated test fleet consists of 15 durability and 38 emission test vehicles. This represents about 65 percent of GM's LDV emission fleet. This results in a certification cost of about $10 million based on the previously extrapolated cost of $.2 million per test vehicle.

A significant cost would be incurred by each manufacturer producing the types and weight ranges of vehicles considered. Even assuming that the above cost is high by a factor of two, a manufacturer whose total sales were 50,000 units would have an average cost of about $100 per vehicle sold.

TABLE 3.23

CERTIFICATION FLEET REQUIREMENTS *

6,000 - 10,000 GVW

ENG. FAM.	CID	EM. CONT.	% SALES	BODY TYPE	CERTIFICATION FLEET			
					D	A	B	C
I6-1	225-249	A	100	P	1	1		
				V/P		1	1	
				MS				
				CH/MH			1	
I6-2	250-300	A	100	P	1	1	1	
				V/P		1		
				MS			1	
				CH/MH				
V8(3)-1	300-320	A	100	P	1	1	1	
				V/P		1		
				MS			1	
				CH/MH			1	
V8(3)-2	330-360	A	100	P	1	2		
				V/P				
				MS				
				CH/MH			1	
V8(4)	390-400	A	100	P	1	2		
				CH/MH			1	
			TOTALS		5	10	9	

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*Based on 1974 LDV certification procedures

TABLE 3.24

CERTIFICATION FLEET REQUIREMENTS *

10,000 - 14,000 lbs. GVW

ENG. FAM.	CID	EM. CONT. SYS.	% SALES	BODY TYPE	CERTIFICATION FLEET D	A	B	C
I6-1	225-249	A_1	10	MS	1		1	
	225-249	B_1	90	CH/MH	1	2	1	
I6-2	250-300	A_1	50	MS	1	1	1	
	250-300	B_1	50	CH/MH	1	1	1	
V8(3)-1	300-320	A_1	9	MS	1		1	
	300-320	B_1	91	CH/MH	1	2	1	
V8(3)-2	330-360	A_1	28	MS	1		1	
	330-360	B_1	72	CH/MH	1	2	1	
V8(4)	390-500	A_1	15	MS	1		1	
	390-500	B_1	85	CH/MH	1	2		
			TOTAL		10	10	9	

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*Based on 1974 LDV certification procedures.

The preceding data are believed to be indicative of the magnitudes of certification costs which may be encountered. As noted in the introductory paragraph of section 3.7.1, the development of precise estimates requires specific information which is not presently available. Nevertheless, the sample analysis demonstrates that certification costs for medium duty vehicles could have a significant impact on the total system costs; particularly for the smaller manufacturers.

One final qualification is in order. The majority of the vehicles which would be certified in the MDV class are presently certified using the Heavy Duty engine procedure. A more precise analysis of MDV certification costs would have to consider the cost increment associated with MDV certification over present Heavy Duty certification costs.

3.7.2 Consumer Costs

The most expensive system considered results in a $.02 incremental cost increase per mile based on 50,000 miles of travel. For most of the systems, the cost increase due to the addition of emission control devices is in the order of $.005 to $.01 per mile. The use of diesel engines results in lower costs than are incurred with the baseline engines.

Discussions with local truck leasing agencies indicated that the additional costs of emission control devices would have little or no direct impact on consumer prices. The current pricing structure is such that a class of vehicles which are leased at a given price include vehicles whose sticker prices may vary considerably. A similar situation is also encountered in light duty vehicle rentals where full-sized, low-priced vehicles are leased at the same rates as some models of the medium-priced.

No direct relationship between sticker prices and operating costs versus leasing rates were found. The latter are a function of many factors important among which are demand and competition. Based on the available evidence it is concluded that the addition of emission control devices on medium duty vehicles will not impact significantly on the user or leasing costs of these vehicles.

Time and data restrictions did not permit alternative investigations of the impact of emission control systems on consumer costs.

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8. Telcom with John Mapleback, Ford Motor Co., 8 March 1973.

9. Effect of Lead Antiknocks on the Performance and Costs of Advanced Emission Control Systems, E. I. Dupont de Nemours & Co., Inc., July 1971.

10. Telcom with Charles Bailey, Universal Oil Products, 9 March 1973.

11. Letter to John P. DeKaney from Fred W. Bowditch, 22 Dec. 1972, Subject: GM Cost Information on Advanced Emission Control Systems under Development.

12. Information provided by R. Kruse, EPA, Ann Arbor, Michigan.

13. Final Report, Assessment of Domestic Automotive Industry Production Lead Time for 1975/1976 Model Years, Aerospace Corp., 15 December 1972.

14. Telcom with Mr. Feiton, General Motors Corp., April 1973.

APPENDIX A-1

COMPARISON OF SPECIFICATIONS FOR ENGINES USED IN LDV AND HDV APPLICATIONS

The same basic engine families are generally used by the automobile manufacturers in their passenger cars and light duty vehicles (under 6,000 lbs GVW) and in their medium duty trucks (6,000-14,000 lbs GVW). Engine families are designated by the manufacturers as comprised of those engines that share a common engine block casting; identical cylinder arrangement, bore spacing and deck height. Engines classified within a given family may have different displacements resulting from changes in bore and/or stroke dimensions. Similarly, horsepower ratings of engines with a given displacement may be found to differ because of changes in carburetion, compression ratio, camshaft lift and/or duration, etc.

Tables A-1.1 through A-1.4 provide a comparison of the engines used by Chrysler, Ford, General Motors and International Harvester in their light duty and medium duty vehicles. These data were culled from information submitted by each manufacturer to EPA in their LD and HD Gasoline Engine Certification Books on 1973 models. Within any one family, all of the light duty engines are included whereas, in the heavy duty families, only those engines used in vehicles with GVW ratings between 6,000 and 14,000 lbs are listed. A listing of the emission control devices used on each is given as well.

Generally, the heavy duty engines are equipped with fewer external emission control devices and are rated at a slightly higher power output. Close scrutiny of the detailed specification sheets in the source documents showed that, with few exceptions, the LD and HD engines were identical internally (same camshafts, heads and compression ratios). Such internal differences as were noted were relatively minor. One example would be a difference in exhaust valve material.

Emission controls used on the heavy duty engines are seen to be taken directly from their light duty counterparts. Engine modifications and

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positive crankcase ventilation systems are used by all engines listed. Those heavy duty engines sold in California are equipped with EGR and evaporative control systems to comply with the 1973 standards for that state.

Emission control devices are identified only by their acronyms in Tables A-1.1 through A-1.4. Table A-1.5 identifies these acronyms according to their meaning and provides a brief description of the purpose and functioning of the control devices.

TABLE A-1.1 ENGINE COMPARATIVE DATA

1973 Chrysler Corp. Light Duty Engines vs Chrysler Corp. Heavy Duty Engines

Engine Family	Engine Type	Displacement	Carburetion	Light Duty		Heavy Duty		Note
				HP @ RPM	Control Devices	HP @ RPM	Control Devices	
RG	I 6	198	1 - 1 BBL	95 @ 4000	PCV,OSAC,EGR,CAN			
"	"	225	1 - 1 BBL	98 @ 4000	PCV,OSAC,EGR,CAN,AI	110 @ 4000	PCV,EM,CAN	A,B,C
"	"	"	"	105 @ 4000	"			A,B
LA	V 8	318	1 - 2 BBL	150 @ 3600	PCV,OSAC,TIDC,EGR,CAN	150 @ 4000	PCV,EM,CAN	A,C,D
"	"	"	"	170 @ 4000	"	160 @ 4000	"	A,C,D
"	"	340	1 - 4 BBL	240 @ 4800	PCV,OSAC,TIDC,EGR,CAN			
"	"	360	1 - 2 BBL	163 @ 4000	PCV,OSAC,TIDC,EGR,CAN,AI	180 @ 4000	PCV,EM,CAN	A,B,C,D
"	"	"	"	170 @ 4000	"			B,C,D
B	V 8	400	1 - 2 BBL	175 @ 3600	PCV,OSAC,TIDC,EGR,CAN	200 @ 4400	PCV,EM,CAN	C,D
"	"	"	"	185 @ 3600	"			D
"	"	"	1 - 4 BBL	260 @ 4800	PCV,OSAC,TIDC,EGR,CAN			D
RB	V 8	413	1 - 4 BBL			205 @ 3600	PCV,EM,CAN	C
"	"	440	1 - 4 BBL	208 @ 3600	PCV,OSAC,TIDC,EGR,CAN,AI			B,D
"	"	"	"	213 @ 3600	"			B,D
"	"	"	"	215 @ 3600	"			B,D
"	"	"	"	220 @ 3600	"			B,D
"	"	"	"	280 @ 4800	PCV,OSAC,TIDC,EGR,CAN			D

NOTES: A - Light Duty Engines have electronic ignition systems as standard equipment while heavy duty engines have electron ignition as an option or standard only in California

B - Light duty engines have air injection only on California models

C - Heavy duty engines have evaporative controls (CAN) only on California models

D - Light duty engines have TIDC systems only on air-conditioned or air injected models

TABLE A-1.2 ENGINE COMPARATIVE DATA

1973 Ford Light Duty Engines vs Ford Heavy Duty Engines

Engine Family	Engine Type	Displacement	Carburetion	Light Duty		Heavy Duty		Note
				HP @ RPM	Control Devices	HP @ RPM	Control Devices	
240-300	I 6	240	1 - 1 BBL	95 @ 3800	PCV,TCS,EGR,CC			
"	"	"	"	99 @ 3800	"			
"	"	300	1 - 1 BBL			114 @ 3400	IMCO,PCV,CC	C
"	"	"	"			117 @ 3600	"	C
"	"	"	"			118 @ 3400	"	C
"	"	"	"			126 @ 3400	"	A,C
302	V 8	302	1 - 2 BBL	140 @ 4000	PCV,SDV,EGR,CC	139 @ 3800	IMCO,PCV,CC	C
330-361-391	V 8	330	1 - 2 BBL			137 @ 3200	IMCO,PCV,CC	A,C
360-390	V 8	360	1 - 2 BBL	152 @ 4000	PCV,SDV,EGR,CC	148 @ 3800	IMCO,PCV,EGR,CC	B,C
"	"	"	"	153 @ 4000	"			
"	"	390	1 - 2 BBL	162 @ 4000	PCV,SDV,EGR,CC	153 @ 3400	IMCO,PCV,EGR,CC	B,C
"	"	"	"			161 @ 3600	"	"

NOTES: A - The 126 HP, 300 cu in six and the 330 cu in V-8 are available only in the F-500 and heavier trucks. The GVW ratings of the F-500 start at 14000#.

B - The heavy duty versions of the 360 and 390 cu in V-8's have exhaust gas recirculation systems in California only.

C - Heavy duty versions of these engines have carbon canister (CC) evaporative controls in California only, on fuel systems with a total capacity of 50 gallons or less.

TABLE A-1.3 ENGINE COMPARATIVE DATA

1973 Chevrolet (GMC) Light Duty Engines vs Chevrolet (GMC) Heavy Duty Engines

Engine Family	Engine Type	Displacement	Carburetion	Light Duty		Heavy Duty		Note
				HP @ RPM	Control Devices	HP @ RPM	Control Devices	
102*& 111**	I 6	250	1 - 1 BBL	100 @ 3600	PCV,AI,EGR,GMECS	100 @ 3600	PCV,CCS	A
112**	I 6	292	1 - 1 BBL			120 @ 3600	PCV,CCS,GMECS	B,C
104*& 113**	V 8	307	1 - 2 BBL	115 @ 3600	PCV,AI,EGR,GMECS	130 @ 4000	PCV,CCS,GMECS	C
"	"	350	1 - 2 BBL	115 @ 4000	PCV,AI,EGR,GMECS	155 @ 4000	PCV,CCS,GMECS	C
"	"	"	"			160 @ 4000	"	C
"	"	"	1 - 4 BBL	155 @ 4000	PCV,AI,EGR,GMECS	155 @ 4000	PCV,CCS,GMECS	C
"	"	"	"	175 @ 4000	"			
"	"	"	"	190 @ 4400	"			
"	"	"	"	245 @ 5200	"			
"	"	"	"	250 @ 5200	"			
"	"	400	1 - 2 BBL	150 @ 3200	PCV,AI,EGR,GMECS			
105*& 115**	V 8	454	1 - 4 BBL	215 @ 4000	PCV,AI,EGR,GMECS	240 @ 4000	PCV,CCS,AI,GMECS	D
"	"	"	"	240 @ 4000	"	250 @ 4000	"	D
"	"	"	"	245 @ 4000	"			
"	"	"	"	275 @ 4400	"			

NOTES: A - The heavy duty version of the 250 cu in six is not for sale in California.

B - The 292 cu in six block is identical to the 250 cu in six block except for deck height (292-10.875",250-9.150")

C - The heavy duty versions of these engines have evaporative controls (GMECS) in California only.

D - The heavy duty version of the 454 cu in V-8 has air injection and evaporative controls in California only.

* - Light Duty Engine Family

** - Heavy Duty Engine Family

TABLE A-1.4 ENGINE COMPARATIVE DATA

1973 International Harvester Light Duty Engines vs International Harvester Heavy Duty Engines

Engine Family	Engine Type	Displacement	Carburetion	Light Duty		Heavy Duty		Note
				HP @ RPM	Control Devices	HP @ RPM	Control Devices	
6 - 258	I 6	258.114	1 - 1 BBL	140 @ 3800	PCV,AI,EGR,SCS,CC			
V - 304	V 8	303.68	1 - 2 BBL	193 @ 4400	PCV,AI,EGR,SCS,CC	193 @ 4400	PCV,EM,EGR	A
V - 345	V 8	344.96	1 - 2 BBL	197 @ 4000	PCV,AI,EGR,SCS,CC	197 @ 4000	PCV,EM,EGR	A
V - 392	V 8	390.89	1 - 4 BBL	253 @ 4200	PCV,AI,EGR,SCS,CC	253 @ 4200	PCV,EM	

SCS - Speed Controlled Spark

NOTES: A - The heavy duty versions of these engines have exhaust gas recirculation systems only on California engines

TABLE A-1.5 - SUMMARY OF EMISSIONS CONTROL DEVICES PRESENTLY USED

Abbreviation	Syst em Name	System Description
PCV	Positive Crankcase Ventilation System	A system which supplies fresh air to the crankcase through the air filter and directs the blow-by gases into the intake manifold through a spring-loaded metering valve.
AI	Air Injection System	A system consisting of an engine-driven air pump which supplies fresh air to nozzles located in the exhaust ports, completing combustion of hydrocarbons externally. The systems usually incorporate some flow control devices for better driveability.
EGR	Exhaust Gas Recirculation System	A system which controls oxides of nitrogen (NO_x) emissions by recirculating a portion of the exhaust gases back into the intake manifold. The plumbing consists of fixed orifices or vacuum-controlled valves.
TCS	Transmission Controlled Spark	All of these systems are ignition modifications to control spark advance under various speed or load conditions.
SDV	Spark Delay Valve	
OSAC	Orifice Spark Advance Control	
TIDC	Thermostatic Ignition Distributor vacuum Control	
GMECS	General Motors Evaporative Control System	All of these systems are evaporative emissions control systems consisting basically of a charcoal or carbon filled canister into which the evaporated hydro carbons from the gas tank and carburetor are directed. They are held here until the engine is started at which time they are purged into the intake manifold
CC	Carbon Canister	
CAN	CANister evaporative control	
EM	Engine Modifications	These systems, used on heavy duty engines, consist mainly of modifications and recalibrations made on basically unchanged pre-emission controls engines. The carburetor and choke are modified, the spark advance curve is altered, the compression ratio is lowered, the head design is altered, a system to pre-heat intake air is installed, the camshaft profile is altered, etc.
CCS	Controlled Combustion System	
IMCO	IMproved CObustion System	

APPENDIX A-2

A SUMMARY OF EXHAUST EMISSIONS DATA FROM MEDIUM DUTY VEHICLES 6,000 - 14,000 POUNDS GVW

This appendix simply presents a tabular summary of the exhaust emissions data for motor vehicles in the nominal 6,000 - 14,000 pound GVW range. These data were measured by EPA and its two contractors, Southwest Research Institute (SWRI) and Automotive Engineering Systems, Inc. (AESI), using an equivalent 1975 Federal Test Procedure. The only deviations from the 1975 FTP occurred in the determination of vehicle inertia weight and vehicle road load horsepower.

Inertia weight was obtained by adding an incremental weight to the curb weight of the vehicle and rounding this sum to the nearest 500 lbs. The incremental weight to be added was established by reference to the following table.

Incremental Weight (lbs)	Vehicle Payload Capacity (GVW-GCW)
500	2000 lbs
1000	2000-4000 lbs
1500	4000 lbs

With the inertia weight established, the corresponding road load horsepower to be used for that vehicle was calculable from the following relation.

$$\text{Road load HP} = 0.0096\ (\text{inertia weight lbs}) - 30.3$$

The attached sheets itemize the data by the test organizations vehicle number; vehicle model year; vehicle make, model year and body type; GVW, GCW and inertia weight, engine displacement and number of cylinders; averaged emissions for HC, CO, CO_2 and NO_x in grams per mile; number of

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tests averaged and whether the engine had been tuned prior to the test.

Data for 122 vehicles are listed and of this total 12 are motor homes. The preponderant body type vehicle sampled was the pickup/camper. Approximately 75% of these vehicles were 1970 and later models. Excluding motor homes, approximately 55% of all vehicles were tested at an inertia weight of 5000 and 5500 pounds and only 6% in the range above 8000 pounds.

Vehicles numbered 1 through 67 were tested by EPA as a part of an in-house study. Vehicles numbered 200 through 245 were tested by SWRI while those coded 1A through 45A (the letter A was arbitrarily added to differentiate from the EPA group of vehicles) were tested by AESI.

Generally all 1972 and 1973 model vehicles were tested after the engine had been "tuned". In the earlier stages of the test programs, the tuning only involved setting the idle rpm to specifications. Later, the tuning procedure was extended to include adjustment of the initial timing and the dwell angle.

EPA

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile HC	CO	CO_2	NO_x	No. of Tests	Eng. Tuned
1	72	Chev.	C-20	Pickup	7,500	4,385	5,000	350-8	3.14	19.32	875.88	4.88	2	No
2	66	Dodge	D-100	Pickup	5,200	3,620	4,000	225-6	3.05	49.92	591.11	5.70	2	No
3	71	AMC	J4000	Pickup	7,000	4,265	4,265	360-8	6.05	24.44	945.76	7.66	2	No
4	68	Dodge	B300	Van	7,700	5,565	6,500	318-8	5.52	56.02	697.69	9.43	2	No
5	71	I-H	-	Multi-Stop	6,100	4,295	5,000	232-6	4.02	65.18	698.50	5.63	2	No
6	72	Ford	F-350	Van	10,000	6,620	7,500	300-6	2.89	43.67	955.35	10.77	2	No
7	72	Chev	P-35	Van	10,000	6,760	7,500	350-8	3.86	65.46	1144.03	9.32	2	No
8	72	Ford	E-300	Van	6,050	4,110	4,500	240-6	2.76	28.78	682.94	5.40	2	No
9	72	Dodge	D-300	Pickup	9,000	5,185	6,000	400-8	3.58	57.44	851.52	5.91	2	No
10	70	Dodge	-	Motor Home	10,000	8,645	9,000	318-8	9.32	158.98	1082.03	14.85	4	No
11	72	Chev	C-35	Stake	10,000	5,395	7,500	350-8	2.43	29.82	1240.35	9.02	2	No
12	72	Ford	F-250	Pickup	6,900	4,460	5,000	360-8	4.43	26.46	842.47	12.63	4	No
13	71	Dodge	D-300	N/A	10,000	5,575	6,000	318-8	4.83	58.52	952.37	9.99	4	No
14	69	Ford	E-300	Van	6,800	4,170	4,500	240-6	6.87	14.65	560.53	5.38	2	No
15	71	Chev	C-30	N/A	10,000	5,580	6,000	350-8	6.13	79.32	767.81	9.45	4	No
16	70	Ford	E-300	Van	6,500	4,235	4,500	240-6	4.55	39.32	627.09	6.67	4	No
17	67	Ford	F-350	N/A	10,000	6,630	7,000	300-6	6.48	65.75	872.67	15.97	2	No
18	72	Chev	C-20	Pickup	10,000	6,770	7,500	350-8	5.32	47.26	976.68	12.04	4	No
19	72	Ford	F-250	Pickup	6,900	4,120	4,500	300-6	2.50	29.57	631.80	10.95	4	No
20	71	Chev	C-30	Van	10,000	6,820	7,500	350-8	5.19	61.39	1058.20	12.44	4	No
21	69	GMC	Sierra Grande	Pickup	7,500	4,730	5,000	396-8	6.95	83.64	734.11	7.03	2	No
22	71	Chev	C-20	Pickup	6,200	4,920	5,500	350-8	5.97	37.05	757.78	8.56	2	No
23	65	Chev	C-20	Pickup	7,500	4,325	5,000	250-6	7.69	70.49	532.08	8.99	2	No
24	69	Ford	F-250	Motor Home	6,100	6,315	7,000	360-8	8.06	116.06	934.45	15.82	3	No
25	71	Ford	E-300	Van	7,600	5,840	6,500	302-8	9.35	59.00	786.11	15.55	2	No
26	71	Ford	E-300	Van	6,050	4,340	5,000	302-8	6.94	73.95	695.26	6.58	2	No
27	68	Ford	F-250	Pickup	7,500	4,620	5,000	240-6	8.49	94.47	569.85	6.53	2	No

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile				No. of Tests	Eng. Tuned
									HC	CO	CO_2	NO_x		
28	70	Chev	C-20	Pickup	7,500	4,900	5,500	350-8	4.97	36.06	801.89	12.77	2	No
29	70	Ford	F-250	Camper	6,900	7,150	5,500	360-8	5.65	78.05	790.79	10.19	2	No
30	66	Chev	C-20	Pickup	7,500	4,405	5,000	283-8	13.00	114.47	609.73	6.33	2	No
31	68	GMC	C-25	N/A	7,500	5,125	5,500	327-8	7.65	99.21	735.49	10.75	2	No
32	72	Dodge	B-300	Van	7,000	4,160	4,500	360-8	3.91	31.01	734.86	7.60	2	No
33	66	Chev	C-20	Pickup	7,500	4,500	5,000	250-6	9.86	65.94	669.98	13.19	2	No
34	71	Ford	N/A	Camper	6,900	4,920	5,500	360-8	8.17	111.56	670.72	7.01	2	No
35	71	Chev	C-30	Camper	9,000	4,198	4,500	400-8	4.10	43.82	910.68	11.01	3	No
36	69	Ford	F-250	Pickup	6,900	4,600	5,000	360-8	12.45	106.61	710.96	6.94	2	No
37	72	Ford	F-250	Pickup	8,100	4,675	5,000	360-8	6.35	75.28	728.02	7.97	4	No
38	65	Chev	C-20	Pickup	7,500	4,650	5,000	283-8	-	-	-	-	1	No
39	71	Ford	F-250	Pickup	7,500	5,100	5,500	360-8	8.06	98.39	760.73	5.67	2	No
40	71	Chev	C-20	Pickup	6,400	4,880	5,000	307-8	6.41	48.78	737.17	10.06	2	No
41	71	Chev	C-20	Camper	6,700	4,600	5,000	350-8	4.06	78.23	713.24	6.12	2	No
42	71	Chev	C-20	Pickup	6,400	4,275	4,500	307-8	4.21	41.72	690.36	7.80	4	No
43	72	Ford	F-250	Pickup	7,800	4,715	5,000	390-8	3.38	38.76	794.52	10.14	4	No
44		Chev	C-30											
45		Chev	C-30											
46		Chev	C-20											
47	72	Ford	F-700	N/A	23,500	8,950	10,000	361-8	6.01	75.80	1185.69	16.38	2	No
48	72	Chev	C-20	Pickup	6,200	4,540	5,000	350-8	3.20	24.19	684.49	7.03	2	Yes
49	72	Ford	F-250	Pickup	7,500	4,495	5,500	250-6	5.23	32.49	737.25	2.78	2**	Yes
50	70	GMC	C-35	N/A	14,000	8,180	10,000	350-8	6.85	86.66	966.76	13.02	2	No
51	69	Chev	C-20	Pickup	7,500	4,540	5,500	350-8	9.70	152.15	639.87	5.48	2	No
52	70	GMC	C-35	N/A	14,000	8,175	10,000	350-8	7.53	83.61	986.91	13.01	2	No
53	72	Dodge	D-300	N/A	10,000	5,200	6,500	318-8	4.61	24.41	806.88	8.80	2	Yes
54	71	Ford	F-350	Van	10,000	7,320	8,500	300-6	6.64	119.87	759.81	9.01	2	No
55	69	Chev	C-20	Pickup	7,500	4,540	5,000	307-8	6.20	31.39	641.15	7.22	2	No
56*	73	Chev		Camper Special	9,000	5,170	6,500	350-8	1.63	28.96	1000.18	5.87	2	Yes
57*	73	Chev	C-20	Pickup	8,200	5,545	7,000	454-8	1.68	11.07	998.32	10.53	2	Yes

*Green Engine

**EGR

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile HC	CO	CO_2	NO_x	No. of Tests	Eng. Tuned
58	69	Chev	C-20	Dump-Bed	10,000		7,500	350-8	8.18	94.33	759.31	8.54	1	No
59	73	Ford	F-250	Pickup	6,200		5,000	360-8	3.51	50.60	760.87	4.67	2	Yes
60	73	Chev	C-20	Pickup	6,400		5,500	454-8	1.58	31.18	1091.85	4.69	2	Yes
61*	73	Chev	C-20	Pickup	6,800		5,500	350-8	2.03	12.47	829.63	6.62	2	Yes
62*	73	Chev	C-20	Pickup	6,400		5,000	250-6	3.30	33.47	710.89	3.68	2	Yes
‡ 63*	73	Chev	C-20	Pickup	6,400		5,000	292-6	3.21	57.59	1041.36	2.50	2	No
									1.28	31.70	740.60	2.32	2	Yes
64	73	IHC	1510	Chassis	14,000		8,000	345-8	6.79	67.43	931.81	4.59	2	Yes
65	73	Chev	P-30	St. Van	8,200		7,000	350-8	2.52	40.51	968.25	7.18	2	Yes
66*	73	Chev	P-30	Barth Mtr.Home	11,000		8,500	454-8	3.61	51.91	1202.20	9.85	2	Yes
67	73	Ford	F-250	Pickup	6,200		5,000	360-8	3.91	31.43	763.70	5.73	2	Yes

‡Start of more extensive tune-up checks   *Green Engine

SWRI

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile				No. of Tests	Eng. Tuned
									HC	CO	CO_2	NO_x		
200	70	Ford	F-250	Pickup	7,500	4,020	5,000	240-6	9.69	139.06	502.33	5.93	2	No
201	69	Chev	C-20	Pickup	7,500	4,430	5,500	292-6	6.18	68.39	508.11	4.81	2	No
202	66	Chev	C-20	Pickup	7,500	4,260	5,500	327-8	39.07	122.61	648.45	4.88	2	No
203	68	Chev	C-20	Pickup	7,500	4,390	5,500	327-8	19.70	236.05	532.02	2.75	2	No
204	71	Chev	C-20	Pickup	7,500	4,400	5,000	350-8	3.48	24.20	717.08	6.82	2	No
205	73	Dodge	N/A	Motor Home	11,000	7,730	8,000	318-8	8.97	126.39	1008.05	12.88	2	Yes
206	71	I-H	1210	Pickup	6,100	4,450	5,000	345-8	6.02	64.91	617.20	4.13	2	No
207	66	I-H	Metro Van-1200	Panel	8,000	5,900	7,000	266-6	18.50	170.41	702.84	5.56	2	No
208	72	I-H	1210	Pickup	7,500	4,710	5,500	304-8	4.72	41.37	677.79	8.47	2	No
									4.35	59.76	734.00	5.14	2	Yes
209	73	Ford	E-300	Van	7,000	4,260	5,500	302-8	5.82	38.40	629.83	4.73	2	No
									5.30	31.87	706.37	3.80	2	Yes
210	70	Chev	C-30	Pickup	8,000	4,990	6,000	292-6	7.11	76.53	655.10	7.21	2	No
211	70	Chev	C-20	Pickup	6,200	5,990	6,500	250-6	6.35	91.58	659.79	8.40	2	No
212	70	Dodge	D-200	Pickup	7,500	4,300	5,500	318-8	5.59	37.40	604.05	5.29	2	No
213	72	Ford	E-300	Van	7,000	4,450	5,500	302-8	4.24	68.51	774.11	4.13	2	Yes
214	72	Ford	E-300	Van	7,000	4,080	5,000	302-8	5.84	40.75	628.82	3.53	2	Yes
215	70	GMC	C-25	Pickup	6,200	4,360	5,000	292-6	5.86	53.20	593.33	7.37	2	No
216	69	Dodge	D-27	Motor Home	12,000	9,820	11,000	318-8	6.02	88.72	757.98	6.34	2	No
217	73	Chev	C-20	Pickup	6,400	4,900	5,500	454-8	5.13	70.52	860.91	4.26	2	Yes
218	72	Chev	C-20	Pickup	6,200	4,340	5,000	350-8	5.34	40.52	634.38	4.97	2	No
									7.01	49.46	636.89	4.82	2	Yes
219	73	Chev	C-30	Van	6,400	4,040	5,000	350-8	5.23	45.10	820.52	4.04	2	Yes
220	70	Ford	F-350	Stake	10,000	6,000	7,500	300-6	4.01	72.78	855.51	11.45	2	No
221	72	Ford	E-300	Motor Home	8,300	6,580	7,500	302-8	5.55	72.23	818.19	7.26	2	Yes
222	72	Dodge	C-300	Stake	10,000	5,350	7,500	318-8	8.24	77.66	846.14	6.77	2	No
									8.00	79.97	793.44	5.13	2	Yes
223	72	GMC	C-35	Wrecker	9,000	5,590	7,500	350-8	9.95	82.11	523.44	7.03	2	Yes

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile				No. of Tests	Eng. Tuned
									HC	CO	CO_2	NO_x		
224	70	Ford	F-250	Pickup	6,100	5,000	5,500	360-8	9.90	126.58	855.21	4.00	2	No
225	67	Ford	F-250	Pickup	6,100	5,100	6,000	240-6	10.23	146.27	707.96	2.66	2	No
226	67	Ford	F-250	Pickup	6,100	5,100	6,000	240-6	13.42	145.05	719.13	2.30	2	No
227	72	I-H	1210	Travel-All	7,500	5,380	6,500	345-8	5.22	67.33	613.69	5.98	2	Yes
228	72	Chev	C-20	Pickup	6,200	4,800	5,500	350-8	3.19	56.82	527.89	7.46	2	Yes
229	67	I-H	1200	Crewcab Pickup	7,300	4,820	6,000	241-6	13.68	128.98	844.30	3.50	2	No
230	67	Chev	C-20	Pickup	7,500	6,000	6,500	250-6	12.16	118.45	611.02	6.00	2	No
231	65	Ford	F-350	Platform	10,000	7,120	8,200	240-6	20.95	182.82	630.76	5.27	2	No
232	71	Ford	F-350	Platform	10,000	7,210	8,200	360-8	12.85	116.28	749.96	6.93	2	No
233	68	Chev	C-20	Pickup	7,500	4,190	5,000	307-8	11.00	135.10	482.41	1.22	2	No
234	68	Ford	F-250	Pickup	7,500	4,490	5,500	240-6	7.56	78.97	477.71	5.67	2	No
235	72	GMC	P-35	Van	7,500	6,960	7,500	292-6	5.35	79.61	788.42	7.22	2	Yes
236	66	Ford	F-250	Pickup	7,500	5,100	6,000	240-6	10.97	140.10	519.29	1.78	2	No
237	69	Ford	F-250	Pickup	6,100	4,500	5,000	360-8	8.04	103.50	582.09	2.81	2	No
238	73	Ford	E-300	Econo. Panel P. U.	8,300	4,340	5,500	302-8	6.21	47.22	566.46	5.69	2	Yes
239	71	Chev	C-20	Pickup	6,200	4,500	5,000	350-8	5.63	50.27	656.20	5.01	2	No
240	73	I-H	1310	Pickup	10,000		7,500	304-8	10.88	131.80	859.84	3.16	2	Yes
241	72	Ford	F250	Pickup	6,900		6,000	300-6	6.30	112.03	737.09	8.12	2	Yes
242														
243	72	Winne-Bago	D22	Motor Home	13,000		8,500	413-8	13.96	139.45	1131.14	14.92	2	Yes
244														
245	72	Champion	(Dodge)	Motor Home	11,000		8,500	318-8	8.23	141.49	996.29	11.96	2	Yes

Note: Blank spaces or those marked "N/A" signify that no information was furnished.

AESI

Vehicle No.	Year	Make	Model	Body Type	GVW	GCW	Inertia Wgt.	Engine	Av. Emissions, gm/mile HC	CO	CO_2	NO_x	No. of Tests	Eng. Tuned
1A	72	Ford	F-250	Pickup			4,500	300-6	3.77	47.84	567.36	8.48	2	No
									2.98	32.33	562.13	6.75	2	Yes
3A	73	Chev	G30	Van			4,500	350-8	4.57	47.26	651.80	4.00	2	No
									2.27	23.26	728.21	4.52	2	Yes
5A	73	Ford	Econol.	Van			4,500	302-8	4.31	85.31	648.00	4.55	2	No
									3.05	31.46	711.00	3.90	2	Yes
7A	72	Ford	F-250	Pickup			5,000	360-8	6.23	55.40	745.00	7.36	2	No
									5.13	44.18	728.00	6.35	2	Yes
10A	72	Ford	Econol.	Van			4,500	302-8	6.09	91.68	635.00	3.50	2	No
									5.83	84.73	665.00	3.39	2	Yes
11A	72	Chev	C-20	Pickup			5,500	350-8	4.05	40.34	855.00	9.91	2	No
									3.47	29.90	829.00	10.02	2	Yes
13A	72	Chev	C-20				5,000	350-8	5.36	62.37	642.00	6.85	2	No
									5.41	34.08	674.00	8.13	2	Yes
27A	72	Dodge					5,000	360-8	5.85	118.16	734.00	7.76	2	No
									3.95	68.37	745.00	8.60	2	Yes
35A	73	Ford	F-250	Pickup			5,000	360-8	3.91	53.89	778.89	4.90	2	No
									4.47	97.15	804.94	4.57	2	Yes
39A	73	Dodge	Surveyor	Motor Home	11,000		8,500	413-8	6.97	123.13	1079.16	13.06	2	No
									6.42	109.46	1145.59	13.02	2	Yes
40A	73	Dodge	Surveyor	Motor Home	11,000		8,500	413-8	10.49	196.56	1251.17	16.98	2	No
									7.30	231.95	1113.84	9.63	2	Yes
43A	72	I-H	1510	Box Van	14,000		6,000	345-8	7.46	54.06	771.92	8.44	2	No
									5.58	51.69	874.88	7.02	2	Yes
44A	72	Ford	Condor	Motor Home	15,000		8,500	390-8	7.45	89.54	1082.22	15.74	2	No
									5.34	82.86	1253.81	15.58	2	Yes
45A	72	I-H	Winne-Bago	Motor Home	13,000		8,500	304-8	12.61	47.50	1124.63	17.61	2	No
									5.29	68.66	1188.56	17.51	2	Yes

APPENDIX A-3

EVAPORATIVE EMISSIONS

In carburetted, gasoline-fueled motor vehicles, the venting of fuel vapors into the atmosphere from the carburetor and the fuel tank constitutes a significant source of HC emissions in the absence of any control devices. It has been estimated that evaporative losses account for approximately 20% of the total HC emissions from an uncontrolled (pre-1968) light duty vehicle.(1) This factor would obviously increase greatly in the situtation where the exhaust emissions were systematically decreased while no control was exercised over the evaporative sources. This is precisely the situation that exists and will continue to obtain for at least the near future for the medium duty vehicle. At present there are no contemplated Federal standards for evaporative emissions for any motor vehicles other than the light duty group. Only the state of California has imposed evaporative emissions standards for heavy duty vehicles commencing with the 1973 models. While the evaporative emissions have not been controlled for medium duty trucks (except in California, as noted), this class of vehicle has benefitted, insofar as exhaust emission controls are concerned, from the progress made in the light duty class of vehicle via the sharing of many common engines.

The progress in exhaust emission control for MDV can be quantified. Mean hydrocarbon emission from a sample of 585 pre-control light duty vehicles (1957-1967 model years) were found to be 8.94 grams/mile (1975 FTP)(2). On the other hand, the mean level of HC emissions for an MDV at an inertia weight of 4500 lbs, corresponding to a full-size passenger car, is given as 4.7 grams/mile in Figure 2.7 (Section 2.4.3) of this report. Thus even comparing LDV with MDV, a significant reduction of exhaust emission of HC has been identified. As a consequence, the need for evaporative controls for the medium duty class of vehicle is evident.

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Evaporative controls can virtually eliminate HC vapors emitted from the carburetor and fuel tank. Probably the most effective method* of control is through the use of cannisters of activated charcoal to trap and store the fuel vapors. Activated charcoal has strong affinity for HC and can store (on a recycle basis) 30-35 grams per 100 grams charcoal without breakthrough.(3) Typically, a vehicle system will use 700-800 grams of activated charcoal.

The evaporative control system is so designed that during vehicle operation, the tank and carburetor vapors are inducted into the engine and burned. During nonoperative periods, the vapors are stored in the charcoal-filled cannisters. When the engine is restarted, filtered air is used to purge the cannisters of vapors which are metered into the vehicle intake manifold and subsequently burned in the engine.

The problem in evaporative control is simply one of routing all of the vapors into a trap or cannister. Trapping of fuel tank vapors is relatively straightforward since all vents and aperatures are readily identified and controlled. The tank filler pipe is sealed by using a low pressure filler cap ($\approx$2 psi). A relief valve allows air to enter the tank as the fuel is consumed.

Vapors emanating from the carburetor are much more difficult to contain because of the many leak sources associated with this component.(4) Fortunately, this problem is not serious during vehicle operation since the interior of the carburetor is usually at a slightly reduced pressure (relative to atmospheric) so that the vapors are inducted into the engine and burned. Tests reported in Reference 4 show that for one particular vehicle, carburetor losses represented 83% of the total evaporative losses (vehicle not operating).

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* crankcase storage of vapors is feasible but less effective

Tests to measure evaporative emissions follow a procedure (SAE Procedure J171) that is known as the SHED (Sealed Housing for Evaporative Determinations) technique.* Briefly, two types of vapor losses are measured while the vehicle is enclosed in the SHED, those associated with the diurnal soak and with the hot soak. The former involves losses that occur over a one-hour period while the fuel in the tank is raised in temperature in accord with a specified schedule. The latter involves losses, again over a one-hour period, while the vehicle cools following completion of a complete 1975 FTP (CVS-CH) test.

Using SHED techniques, the evaporative losses for 125 non-controlled vehicles tested in Los Angeles were found to average 37.4 grams per test.(2) All LDV models, subsequent to the 1971 model, are required to meet a standard of 2 grams HC per test (by a different test technique)*.

There does not appear to be any reason by medium duty vehicles cannot meet the evaporative emission standards being imposed on light duty vehicles through the simple expedient of adapting the same control techniques. No untoward mechanical problems are visualized. Fuel tank designs with a dead volume (to permit thermal expansion of fuel without forcing the liquid fuel into the vapor storage device), patterned after LDV tanks, would be required.

Concern with the possibility of creating a flammable mixture within the engine compartment as the result of the release of vapors from evaporative controls because of extreme underhood temperatures and high fuel volatility led to a series of investigative measurements several years ago at GM.(5) These measurements showed that the HC concentrations were several times lower than the lean flammability limit. In general the engine compartment concentrations were comparable for the same vehicle whether tested with or without evaporative controls. These data are circa 1969. Such tests would probably need to be repeated in MDV in case thermal reactors would be used for exhaust emission control. The underhood temperatures would be much higher in such a situtation. If a potentially dangerous condition were to be found, appropriate design changes would need to be made.

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* Current EPA certification procedures specify a vapor-trap technique (Federal Register, Vol. 37, No. 221, Nov. 15, 1972) which results in lower numerical values of evaporative emissions than the SHED method because of an inability to trap all the vapors from all sources.

In summary, therefore, it appears that evaporative emission controls can be readily adapted to medium duty vehicles. The fact that all heavy duty trucks (1973 models with fuel tank capacity ≤ 50 gals.) being sold in California are required to have evaporative controls, would substantiate the validity of the foregoing conclusions.

REFERENCES

1. "The Automobile and Air Pollution - A Program for Progress, Part II", U.S. Department of Commerce, December 1967.

2. McAdams, H. T., et al, "Automobile Exhaust Emission Surveillance - A Summary", Calspan Corporation, no number, December 1972.

3. Patterson, D. J. and Henein, N. A., "Emissions from Combustion Engines and Their Control", Ann Arbor Science Publishers, Ann Arbor, Michigan, 1972.

4. Martens, S. W. and Thurston, K. W., "Measurement of Total Evaporative Emissions", SAE Paper 680125.

5. Martens, S. W., "Evaporative Emission Measurements with the Shed - A Second Progress Report", SAE Paper 690502.

APPENDIX A-4

IDENTIFICATION AND DESCRIPTION OF EMISSION CONTROL SYSTEM COMPONENTS

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The emissions control systems evaluated in Section 2.6 for medium duty truck applications are listed in Table 2.10. The various components in the control systems are identified and described briefly in this Appendix.

EI - Electronic Ignition

A breakerless ignition system consisting of a rotor, magnetic pick up coil, and electronic switch assembly. It appears all manufacturers will use electronic ignition systems to improve the durability of emission control systems.

FC - Fast Choke

An electric assist fast choke to reduce the time period in which the engine is running fuel rich during engine warm-up. There will be a continuing series of carburetor/choke modifications to reduce emissions when the engine is cold. FC is intended to represent the first generation of such modifications which will or have appeared on 1973-74 cars.

QHI - Quick Heat Intake

Quick heat intake manifold using hot exhaust gases to vaporize the fuel to minimize choke time during engine warm-up. Rapid warm-up is accomplished by maximizing the available heat energy and minimizing the thermal inertia of the hot spot in the intake manifold.

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AI - Exhaust Manifold Air Injection

Air injection into the cylinder exhaust ports of the engine. This includes an air pump, distribution manifold, and exhaust port liners, but does not include a lined, insulated exhaust manifold.

EGR - Exhaust Gas Recirculation

A portion (5-10%) of the hot exhaust gas is mixed with intake air in the carburetor downstream of the throttle plate. This includes provision for an opening into the carburetor from the exhaust crossover passage and an EGR valve. Complex controlled EGR systems are evolving to tailor the EGR flow to engine operating conditions to improve its effectiveness and to reduce its determental effect on fuel economy and driveability. EGR is part of most of the control systems. It is assumed that as the overall emissions control system becomes more developed and efficient, so will the associated EGR component in it.

IC - Improved Carburetion

Various carburetor improvements are being developed for use with the 1975-76 catalyst systems. It has been found that both to protect the catalyst from over heating and to insure rapid warm-up and good conversion efficiency it is necessary to control the A/F ratio more closely than possible with standard (1971-73) carburetors. This has led to the following carburetor improvements: (1) altitude and temperature compensation and (2) more flexibility in the control of A/F mixture for various engine operating modes. Component IC means the inclusion of these carburetor developments in the control system.

CAI - Air Injection Ahead of Catalyst

Air injection ahead of the oxidizing catalyst to provide a lean mixture into the catalyst. This includes an air pump which is driven at an RPM proportional to that of the engine.

OC - Oxidizing Catalyst

This catalyst (noble or base metal) converts CO and HC to CO_2 and H_2O. It can be either a pellet or monolith type. Estimated catalyst volumes for various engine CID are given in Table 2.11. These volumes are larger than presently being tested in passenger cars but it is felt this increased volume is needed for truck applications. Since at present required catalyst volume is determined purely by cut-and-try, it is difficult to estimate volumes required for various trucks/loads.

RC - Reducing Catalyst

The reducing catalyst converts NO_x to CO_2 and H_2O and must operate in a slightly rich environment. Technology for reducing catalysts is not nearly as well developed as for oxidizing catalysts. If the A/F ratio is too rich, then a significant fraction of the NO_x is converted to ammonia (NH_3) which is subsequently oxidized back to NO_x in the ozidizing catalyst. Hence, the A/F ratio must be controlled within a rather narrow range to maintain good NO_x conversion efficiency in the reducing catalyst. There is very limited information available on which to base a selection of reducing catalyst volume as a function of engine CID. Early work would seem to indicate it should be slightly larger than the oxidizing catalyst. The reducing catalyst is placed nearer the engine than the oxidizing catalyst and often is in a separate container, but not necessarily.

AI/CAI - Controlled Air Injection

When using a dual catalyst system (Figure A-4.1) such as system 4, it is necessary to inject controlled amounts of air both into the exhaust ports and ahead of the oxidizing catalyst. AI/CAI includes the AI and CAI components as well as a means of controlling the fraction of the air to be injected at each location.

EFIC - Electronic Fuel Injection and Control

This system includes injection of fuel into each cylinder intake port with a complex electronic control system (Fig. A-4.2), which senses engine RPM, inlet air temperature and pressure, and exhaust oxygen concentration. There is a feed back loop by which the fuel injection is regulated based on desired exhaust O_2 concentration. This is an advanced system requiring development of hardware, the control logic and the O_2 sensor.

RC/OC - Three-way Catalyst

This single catalyst simultaneously converts NO_x, CO, and HC to CO_2 and H_2O. Engine operation must be maintained very near stoichiometric (14.5 ± .1) to attain good conversion efficiency (80-90%) for all three pollutants. The NO_x conversion efficiency is especially sensitive to A/F ratio. EFIC with feedback and an O_2 sensor is needed to achieve the A/F ratio control required.

LTR - Lean Thermal Reactor

This is a manifold thermal reactor used in conjunction with lean carburetor operation. In that case the engine CO and HC emissions are reasonably low and can be combusted efficiently in the reactor. Since the heat release is quite low, it is necessary that the reactor have good insulation to minimize heat loss. Excellent control of the A/F ratio at all engine operating modes is required so that the carburetor should be at least as sophisticated as the IC system. NO_x emissions are kept low by lean engine operation and further reduced by EGR.

RTR - Rich Thermal Reactor

This exhaust manifold reactor is used with rich carburetion. Relatively high HC and CO engine emissions result in high and rapid heat release in the reactor. The high operating temperatures (2000°F or higher) result in high efficiency for the burning of the HC and CO. NO_x emissions are kept low by operating the engine rich and using EGR to reducing NO_x further.

FIC - Further Improved Carburetion

Advanced carburetor systems are being developed which further improve fuel atomization and A/F ratio control over the complete range of engine operating conditions. The objective is to develop a system which permits liquid fuel operation approaching that possible with a gaseous fuel. Examples of advanced carburetor developments are the Dresserator device tested by Ford (11) and IFC (Integrated fuel control) being developed by GM(10).

IQHI - Improved Quick Heat Intake

Improved quick heat intake represents a further improvement of the QHI system. It would be used with the FIC fuel system to further reduce cold engine emissions.

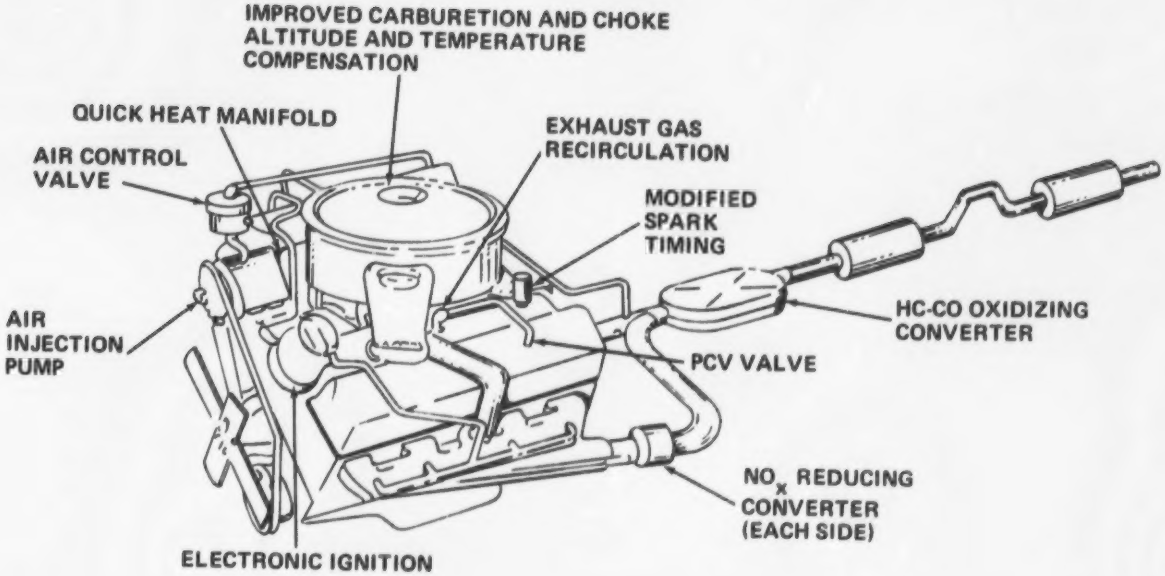

Figure A-4.1 DUAL CATALYST EMISSION CONTROL SYSTEM

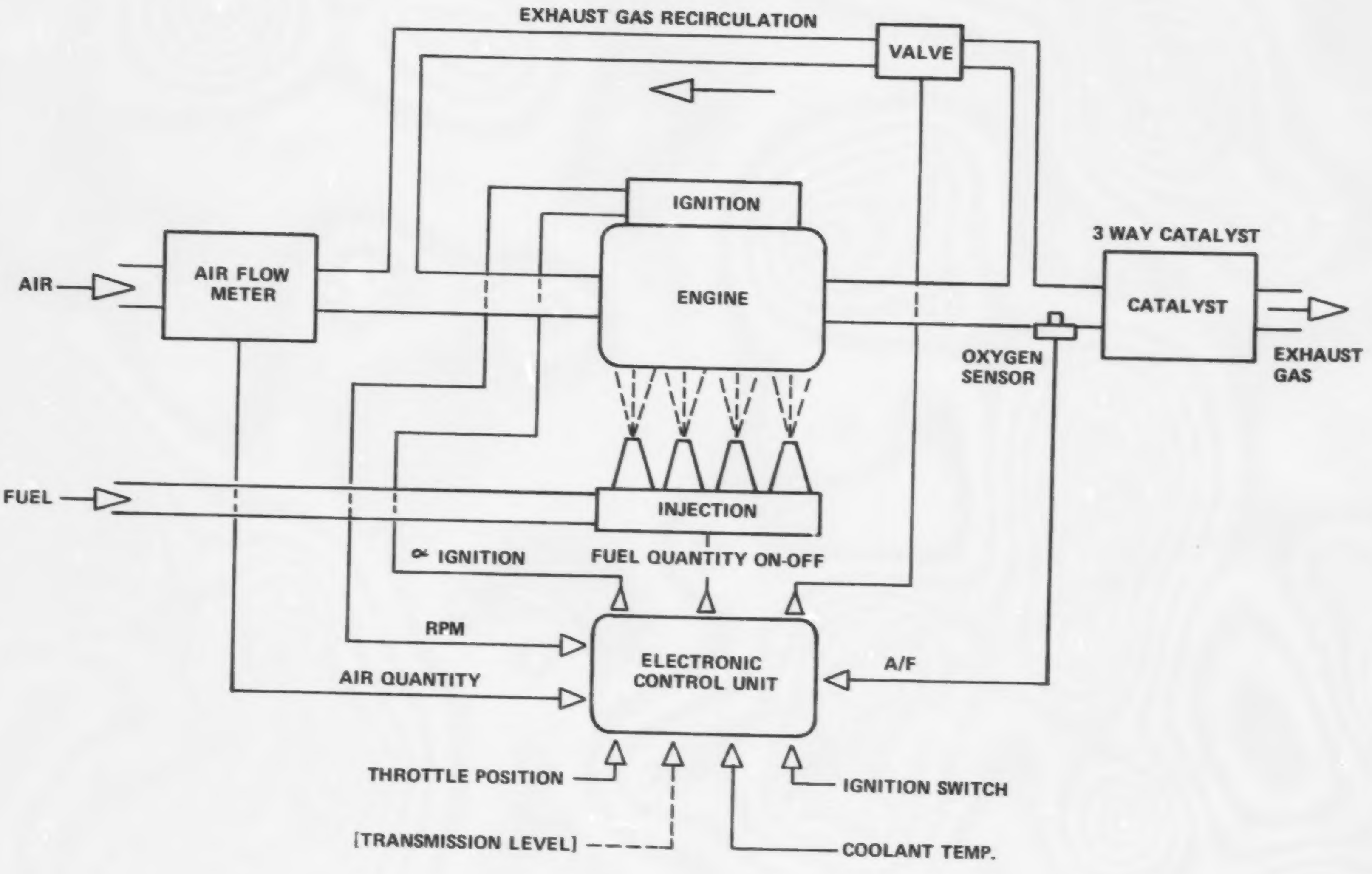

Figure A-4.2 ELECTRONIC FUEL INJECTION AND CONTROL SYSTEM

APPENDIX A-5
SUPPORTING EMISSIONS DATA FOR THE EVALUATION OF THE EMISSION REDUCTION FACTORS

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TABLE A-5.1

SUPPORTING EMISSIONS DATA FOR SYSTEM 2

Source	Control System	Test Weight	1975 CVS-CH Emissions gm/mi HC	CO	NO_x	Number of Tests
Ref (11),	IC + QHI + EGR	5000	1.32	8.35	2.62	16
Ref (11),	IC + QHI + EGR	5000	1.42	9.67	2.2	11
Ref (12),	IC + QHI + EGR	5000	1.24	12.54	1.89	16
Ref (12),	IC + QHI + EGR	4500	1.03	8.43	1.75	4
Ref (10),	IC + QHI + AI + EGR	4500	.90	11.4	2.3	3

TABLE A-5.2

SUPPORTING EMISSIONS DATA FOR SYSTEM 3

Source	AVERAGE 1975 CVS - CH EMISSIONS (gm/mi) HC	CO	NO_x	Number of Vehicles (c)
Ref (12)[a]	.32	1.90	1.95	10
Ref (12)[b]	.32	2.73	2.25	5

(a) GM light duty vehicles

(b) Ford light duty vehicles

(c) Individual vehicles in pre-certification fleet. (test weight 4500 - 5500 lbs.)

TABLE A-5.3

SUPPORTING EMISSIONS DATA FOR SYSTEM 4

(Reference 13)

ADVANCED DUAL CATALYST SYSTEMS - OXIDIZING AND REDUCING CATALYSTS

Car	Eng. Displ.	Mileage on Catalyst*	System Description				1975 CVS-CH Emissions (gm/mi)		
			A.I.	E.G.R.	I.C.	Q.H.I.	HC	CO	NO_x
Vega	140	0-100 R-100	x	x	x	x	.24	1.2	.4
Chev.	350	0-100 R-25	x	x	x	x	.69	3.5	.5
Chev.	350	0-463 R-167	x	x	x		.24	1.7	.2
Chev.	350	0-35 R-45	x	x	x		.44	3.2	.2
Temp.	250	0-30 R-30	x	x	x	x	.40	3.5	.7
Olds.	455	0-1659 R-612	x	x	x		.36	2.7	.4

* 0 - Oxidizing Catalyst Mileage

R - Reducing Catalyst Mileage

TABLE A-5.4
SUPPORTING EMISSIONS DATA FOR SYSTEM 5
(Reference 15)

	Results of 80 Tests	
CVS Emissions [(a)]	Average (gm/mi)	Range (gm/mi)
HC	.15	.1-.25
CO	2.17	1.1-3.3
NO_x	.21	.1-3.5

(a) Data for 1.5-2 liter engines

TABLE A-5.5

SUPPORTING EMISSIONS DATA FOR SYSTEM 6

(Reference 16)

		1975 CVS-CH Emissions, gm/mile	
	HC	CO	NO_x
Modified Cars Make A(1)			
Series 1 Modifications*			
Range	0.5-0.8	5-8	1.1-1.9
Typical Values	0.7	5.5	1.5
Modified Cars Make B(2)			
Series 1 Modifications*			
With Low HC-CO Settings	0.7	6.4	2.2
Series 2 Modifications**			
With Low HC-CO Settings	0.3	3.6	2.3
With Low NO_x Settings	0.6	7.0	1.4

(1) 400 CID, 4000-lb test weight

(2) 360 CID, 4500-lb test weight

*Series 1 Modifications

3-V high-velocity carburetor
Improved carb. air preheat
Modulated EGR
Exhaust port liners
Exhaust reactor
Ignition vacuum-advance regulation

**Series 2 Modifications

Series 1 plus:
Starting sequence device
Quick-heat intake manifold

TABLE A-5.6
SUPPORTING EMISSIONS DATA FOR SYSTEM 7

(Reference 13)

Manifold Reactor	EGR	1975 CVS - CH Emissions Average levels (gm/mi) HC	 CO	 NO_x	Fuel Economy Loss
Dupont	Yes	.09	7.2	.80	25%
II EC Package A	Yes	.22	3.9	.62	24%
GM Modified Dupont	No	.15	5.8	.78	28%
GM Emiss. Research No.1	No	.12	7.5	.77	32%
GM Small Volume	No	.18	4.3	.60	38%
GM Sand Insulated	Yes	.18	3.9	.70	24%
GM Ceramic	No	.10	8.4	.86	-
GM Inboard Reactor	Yes	.11	3.3	.80	31%

TABLE A-5.7

SUPPORTING EMISSIONS DATA FOR SYSTEM 8

Source	Control System	1975 CVS - CH Emissions Average Levels (gm/mi) HC	CO	NO_x	Number of Tests
Ref. (11)	FIC [a]	.75	4.20	2.00	7
Ref (12)	IC + IQHI + EGR [b]	.49	4.27	2.24	2
Ref (12)	IC + IQHI + EGR [b]	.43	3.86	1.86	2

(a) Ford data

(b) GM data

APPENDIX A-6

SUPPORTING DATA FOR THE DETERMINATION OF THE FUEL PENALTY FACTOR

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TABLE A-6.1

FUEL ECONOMY DATA FOR SYSTEM 3[a]

Manufacturer	Vehicle Weight (lbs)	% Change in Fuel Economy[c]	Method of Test	Reference
Ford	4700	-14.8	road[d]	(11)
Ford	5760	-2.6	road	(11)
Ford	4950	-1.5	road	(11)
Ford	4500	+25	CVS-CH	(b)
GM	4500	-6.5	CVS-CH	(b)
Chrysler	4500	+7.0	CVS-CH	(b)
		Avg.[e] -1%(loss)		

(a) 1975 pre-certification fleets, catalytic systems.

(b) Change in fuel economy calculated using 1973 certification results and EPA emissions tests of 1975 prototypes of the same class of vehicle.

(c) Change in fuel economy (MPG) from 1973; average over a number of vehicles.

(d) City/suburban driving schedule.

(e) -14.8%, +25% not included in calculation of the average.

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TABLE A-6.2

FUEL ECONOMY DATA FOR SYSTEM 6(4)

	Fuel Economy, mpg			
	City Route(1)	City + Expressway Route(2)	Average	Loss %
Cars Make A:				
Non-Modified 1970	11.5	14.9	13.2	-
Lean Reactor Mod. 1970(3)	10.6	13.5	12.1	8.3
Non-Modified 1973				
As Received	11.3	14.3	12.8	3.0
Without EGR Cut-Off	10.7	13.4	12.1	8.3
Cars Make B:				
Non-Modified 1971	11.1	16.7	13.9	-
Lean Reactor Mod. 1971				
Low HC-CO Settings	11.1	14.7	12.9	7.2
Low NO_x Settings	10.8	14.4	12.6	9.4
Non-Modified 1973	10.3	14.1	12.2	12.2

(1) Average speed 23.4 mph, 2.2 stops per mile, 27.7-mile loop, multiple tests averaged.

(2) Average speed 36.7 mph, 0.36 stops per mile, 18.4-mile loop, multiple tests averaged.

(3) Supplementary data:
Fuel economy during 20,000 miles of consumer-tupe usage by California ARB was 11.34 mph, with air conditioner in normal use.

(4) Reference (16).

APPENDIX A-7

ANALYTICAL METHOD FOR PREDICTING THE EFFECT OF VEHICLE WEIGHT ON EMISSIONS

In this appendix an analytical method is developed to predict the effect of vehicle inertia weight on emissions starting from knowledge of the engine emissions (gm/hr) as a function of load (HP) and engine RPM, vehicle characteristics (weight, frontal area, drag coefficient, rolling resistance, axle ratio, etc.), and driving cycle (average speed, per cent time in acceleration and cruise, etc.).

The road tractive force needed to propel a truck at a given velocity and acceleration can be determined from applying Newton's Law (F = ma) to the truck

$$T \equiv M_T \frac{dV}{dt} + R_{Air} + R_{rolling}$$

where $T \equiv$ Traction force at the wheels

$R_{Air} \equiv$ Air Resistance

$R_{Rolling} \equiv$ Rolling resistance

The required road horsepower follows simply from

$$(HP)\ \text{road} = VT$$

and the engine horsepower from

$$(HP)\ \text{engine} = \frac{(HP)\ \text{road}}{\eta}$$

where η is the effective driveline efficiency. The road horsepower can be calculated from the following equation:

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$$(\mathrm{HP})_{\text{road}} = \frac{1}{550} \left\{ .0668\ WV \frac{dV}{dt} + .0039\ C_D A_F\ \overline{V}^3 + VW\,(K_1 + K_2 V) \right\} \qquad (1)$$

where

W ≡ Vehicle weight (lbs.)

C_D, A_F ≡ Drag coefficient and front area (ft^2) of the vehicle

V ≡ Speed (mph)

$\frac{dV}{dt}$ ≡ Acceleration (mph/sec)

$\overline{V}^3$ ≡ Average of the velocity cubed

K_1, K_2 ≡ Constants in the rolling resistance equation

Equation (1) was evaluated for four vehicles of interest in the present program. The four cases and the associated constants are given below:

Case	Vehicle	C_D	A_F (ft^2)	K_1	K_2
1	Pick-up Truck	.5	29	.015	.00026
2	Van	.65	34	.015	.00026
3	Stop-Van	.65	44	.014	.00022
4	Passenger Car	.45	21	.017	.000334

The vehicle frontal areas were obtained from reference to manufacturer's sketches of vehicle shapes.

It is desired to calculate a mean horsepower for both acceleration and cruise modes appropriate to the LA-4 driving cycle. In order to do this, one requires

V = average velocity in the mode

$\frac{dV}{dt}$ = average acceleration in the mode

$\overline{V^3}$ = average of the velocity cubed in the mode

Such information is conveniently summarized in Reference (23). For the present work, the 5-city composite results are used as they compare quite closely to the LA-4 cycle. Distribution of total time in mode categories data are given below while acceleration and velocity mode data is given in Figures A-2.1 and Table A-7.1.

	5-City Composite	N.Y.C.	LA-4
% Total time, idle	12.87	17.45	13.56
% Total time, cruise	31.83	26.49	27.25
% Total time, acceleration	29.08	29.12	31.73
% Total time, deceleration	26.23	26.95	27.49

TABLE A-7.1

COMPACTED NORMALIZED TOTAL TIME MATRIX FOR 5-CITY COMPOSITE (Reference 23)

Initail Speed, MPH	FINAL SPEED, MPH													
	0	5	10	15	20	25	30	35	40	45	50	55	60	65
0	13.060	0.582	0.559	0.668	1.025	1.891	2.631	2.314	1.321	0.501	0.140	0.052	0.018	0.010
5	0.577	0.746	0.283	0.253	0.299	0.442	0.506	0.427	0.236	0.092	0.028	0.012	0.006	0.002
10	0.419	0.287	0.768	0.345	0.422	0.546	0.519	0.381	0.141	0.051	0.021	0.013	0.007	0.005
15	0.505	0.207	0.303	0.941	0.509	0.589	0.542	0.425	0.244	0.091	0.031	0.023	0.018	0.027
20	0.943	0.286	0.298	0.401	1.633	0.878	0.641	0.357	0.167	0.059	0.030	0.023	0.015	0.008
25	1.829	0.454	0.395	0.465	0.725	3.518	1.246	0.541	0.224	0.083	0.037	0.031	0.024	0.020
30	2.419	0.488	0.441	0.471	0.560	1.136	5.463	1.228	0.354	0.119	0.048	0.038	0.022	0.024
35	2.142	0.394	0.349	0.380	0.311	0.493	1.103	5.255	0.857	0.228	0.066	0.030	0.014	0.017
40	1.267	0.204	0.158	0.182	0.152	0.193	0.318	0.775	3.450	0.483	0.145	0.063	0.028	0.019
45	0.477	0.087	0.064	0.074	0.065	0.072	0.114	0.214	0.443	2.027	0.340	0.134	0.054	0.015
50	0.160	0.026	0.031	0.022	0.027	0.034	0.035	0.059	0.128	0.319	1.535	0.330	0.107	0.040
55	0.085	0.012	0.013	0.011	0.013	0.018	0.023	0.032	0.061	0.109	0.319	1.806	0.324	0.107
60	0.043	0.013	0.006	0.005	0.006	0.007	0.010	0.020	0.020	0.053	0.109	0.323	2.069	0.292
65	0.037	0.014	0.005	0.001	0.002	0.001	0.002	0.008	0.010	0.016	0.031	0.098	0.284	2.291

NORMALIZED MODE MATRIX SUMMARY

Percent Idle = 13.060
Percent Cruise = 31.502
Percent Acceleration = 29.158
Percent Deceleration = 26.303

Using the speed-matrix data given in Table A-7.1, one finds for cruise conditions (look at the diagonal of the matrix) that

$$V_1 = 37 \text{ (mph)}$$

$$\overline{V}_1^3 = 76,700 \text{ (mph)}^3$$

The average speed for acceleration is taken to be equal to the average overall speed (26 mph) for the 5-city composite cycle. From Figure A-7.1 the corresponding mean acceleration is .8 mph/sec. Fortunately the product $V\, {}^{dV}/_{dt}$ does not changemuch as V changes. The velocity data for the average cruise and acceleraton conditions can be summarized as below:

Mode	V_1 (mph)	${}^{dV}/_{dt}$ (mph/sec)	$\overline{V^3}$
Acceleration	26	.8	25,000
Cruise	37	0	76,700

Now that all the input quantities are known, Equation (1) can be evaluated for a range of vehicle weights. The results are shown in Table A-7.2. Note that the horsepower values calculated are those required at the road, and not at the engine. In order to get the engine horsepower, some assumption must be made regarding the driveline efficiency. In the present work, the following values were assumed:

TABLE A-7.2

ROAD AND ENGINE HORSEPOWERS FOR ACCELERATION AND CRUISE MODES

	Acceleration Mode			Cruise Mode		
W	Pick-Up	HP Van	Stop-Van	Pick-Up	HP Van	Stop-Van
4500	18.6 (24.8)	19.9 (26.5)	20.6 (27.2)	15.3 (16.9)	19.5 (21.6)	22.3 (24.8)
6000	23.9 (31.9)	25.2 (33.4)	25.8 (34.2)	17.8 (19.8)	22 (24.4)	24.5 (27.3)
8000	31.0 (41.2)	32.4 (43.0)	32.7 (43.4)	21.1 (23.4)	25.3 (26.0)	27.5 (30.5)
10000	38.1 (50.5)	39.5 (52.5)	39.7 (52.7)	24.5 (27.2)	28.6 (31.7)	30.4 (33.6)
12000	45.2 (60.2)	46.6 (61.8)	46.6 (61.8)	27.8 (30.8)	31.9 (34.4)	33.4 (37.2)
	52.3 (69.5)	53.7 (71.5)	53.5 (71)	31.0 (34.4)	35.2 (39.2)	36.4 (40.5)

Top number ≡ road horsepower
Bottom number ≡ engine horsepower

Values for 4500 lb. passenger car

Acceleration Mode	Cruise Mode
18.5	14.0
(24.7)	(15.5)

Mode	Type of Transmission	Driveline Efficiency (η)
Acceleration (2nd gear)	Manual	87%
	Automatic	75%
Cruise (3rd gear)	Manual	98%
	Automatic	90%

The engine horsepower values are shown in ( ) below the road horsepower values in Table A-7.2.

The engine RPM is related to the wheel RPM by the simple relation

$$\text{Eng. RPM} = (\text{Wheel RPM})\ (\text{GR})$$

where

$$\text{GR} = (\text{AX R})\ (\text{Trans. GR})$$

$$\text{wheel RPM} = 11.7\ V, \quad \text{Wheel rad.} = 1.2'$$

For the two modes of interest, the following axle and gear ratios were used.

	Car		Truck	
Mode	Ax R	Trans. GR	Ax R	Trans. GR
Acceleration	3.0	1.6	4.1	1.6
Cruise	3.0	1	4.1	1

The corresponding engine RPM are given below:

		Eng. RPM	
Mode	Velocity	Car	Truck
Acceleration	26	1450	1970
Cruise	37	1300	1770

Now one is ready to proceed to calculate the emissions.

It is assumed that all the vehicles of interest are powered by a V-8, 350 CID engine and have an automatic transmission. Engine dynamometer emissions data for this engine are given in Reference (22) (designated as 2-3 in that report). Unfortunately, the test cycle included only 1200 and 2300 RPM as shown in Figures A-7.2-4. Intermediate RPM were faired in following the general shape of two bounding data curves. The general approach was to calculate the difference between the emissions from a truck of weight I_w and a reference passenger car of weight 4500 having the same engine. The emissions from the reference passenger car for the LA-4 driving cycle are well known from emissions tests. It is assumed that the trucks are tested in the same LA-4 driving cycle. Hence the total cycle time is 23 minutes and the length of the route is 7.5 miles. Now the incremental emissions from a truck can be written as

$$\Delta E \text{ (gm/mi)} = \left[\left(\frac{\text{gm E}}{\text{hr}} \right)_{\text{truck}} - \left(\frac{\text{gm E}}{\text{hr}} \right)_{\substack{4500 \\ \text{car}}} \right] \frac{\frac{23}{60} \text{ (\% time in mode)}}{7.5 \text{ mi.}}$$

$$E = \text{HC, CO, NO}_x \qquad (2)$$

Equation (2) is applied for both the acceleration and the cruise mode. GM E/hr is obtained from Figures A-7.2-4 using the appropriate values of HP and Eng. RPM. Table A-7.3 shows a typical set of calculations for the Van-truck.

The computed results are compared with the previous baseline correlation as a function of vehicle weight in Figures A-7.5-7. In the case of HC and NO_x the prediction procedure does surprisingly well both in accounting for the effect of vehicle weight and in giving a reasonable estimate of the initial value at I_w = 4500 lbs. In the case of CO, both the trend

TABLE A-7.3

EMISSIONS CALCULATIONS FOR A VAN TRUCK

Engine - 8 cylinders - 350 CID

Acceleration Mode

Eng. RPM = 1900

I_w	HP	CO	$\hat{CO}$	HC	$\hat{HC}$	NO_x	$\hat{NO}_x$
4500	26.5	215	3.2	49	.73	210	3.14
car	24.5	190	2.83	48	.715	180	2.69
6000	33.4	275	4.1	50	.745	310	4.63
8000	43.0	365	5.45	64	.95	490	7.3
10000	52.5	550	8.2	108	1.60	670	10.0
12000	61.8	860	12.8	176	2.53	770	11.5
14000	71.5	1200	18.0	228	3.38	860	12.8

(E) ~ gm/hr

($\hat{E}$) ~ gm/mi

Cruise Mode

Eng. RPM = 1400

I_w	HP	CO	$\hat{CO}$	HC	$\hat{HC}$	NO_x	$\hat{NO}_x$
4500	21.6	150	2.42	73	1.08	160	2.58
car	15.5	120	1.93	67	1.0	100	1.61
6000	24.4	165	2.66	75	1.13	185	2.98
8000	26.0	175	2.82	75	1.13	210	3.38
10000	31.7	260	4.2	82	1.23	285	4.6
12000	34.4	300	4.85	88	1.32	330	5.35
14000	39.2	400	6.4	100	1.61	415	6.7

$\Delta E = (\Delta E)_{\text{accel}} + (\Delta E)_{\text{cruise}}$

with I_w and initial value are much less than the previous prediction. The large discrepancies in the CO results are probably due to cold start effects and the fact that the mean horsepower approach does not account for time spent near rated horsepower where the specific emissions are very high.

360

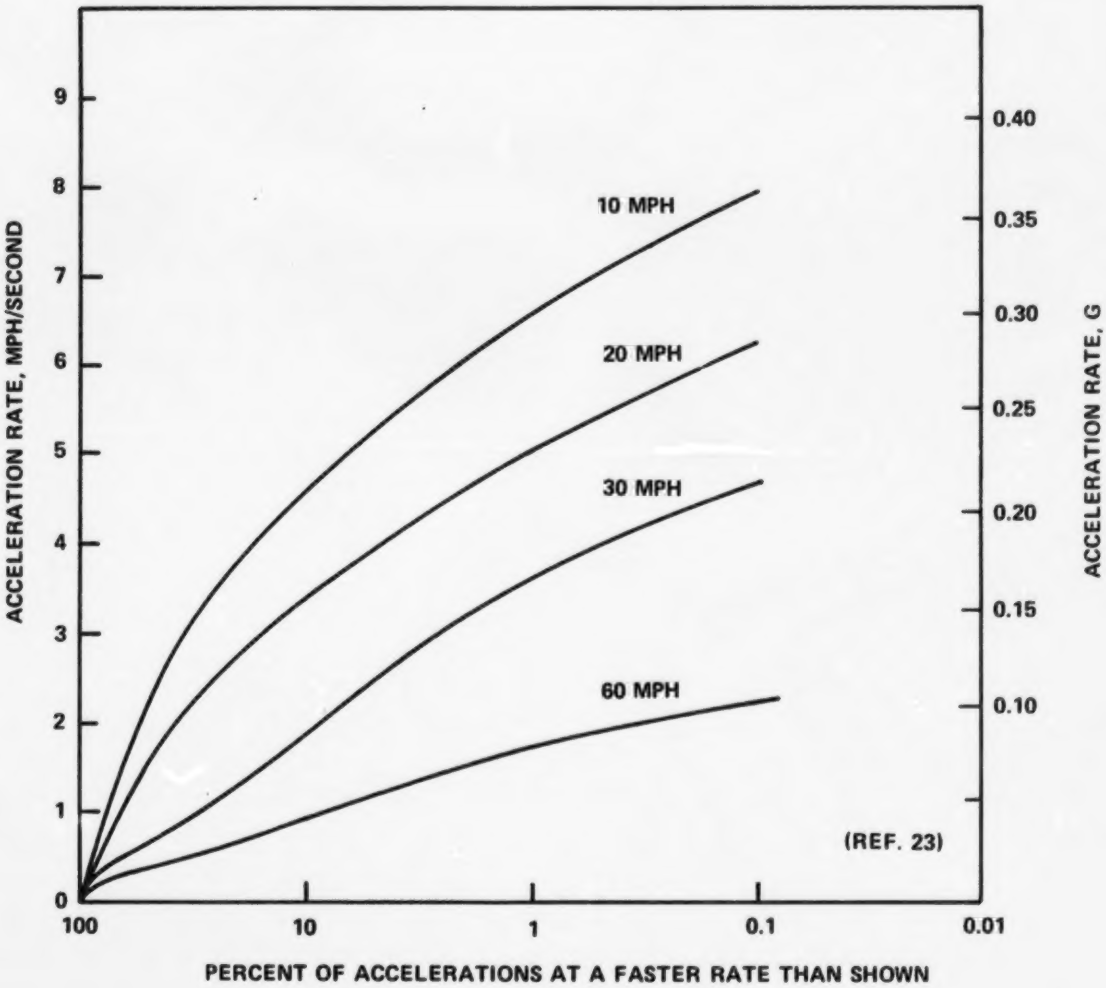

Figure A7.1 DISTRIBUTION FUNCTIONS OF 5-CITY-COMPOSITE ACCELERATIONS AT VARIOUS INSTANTANEOUS SPEEDS

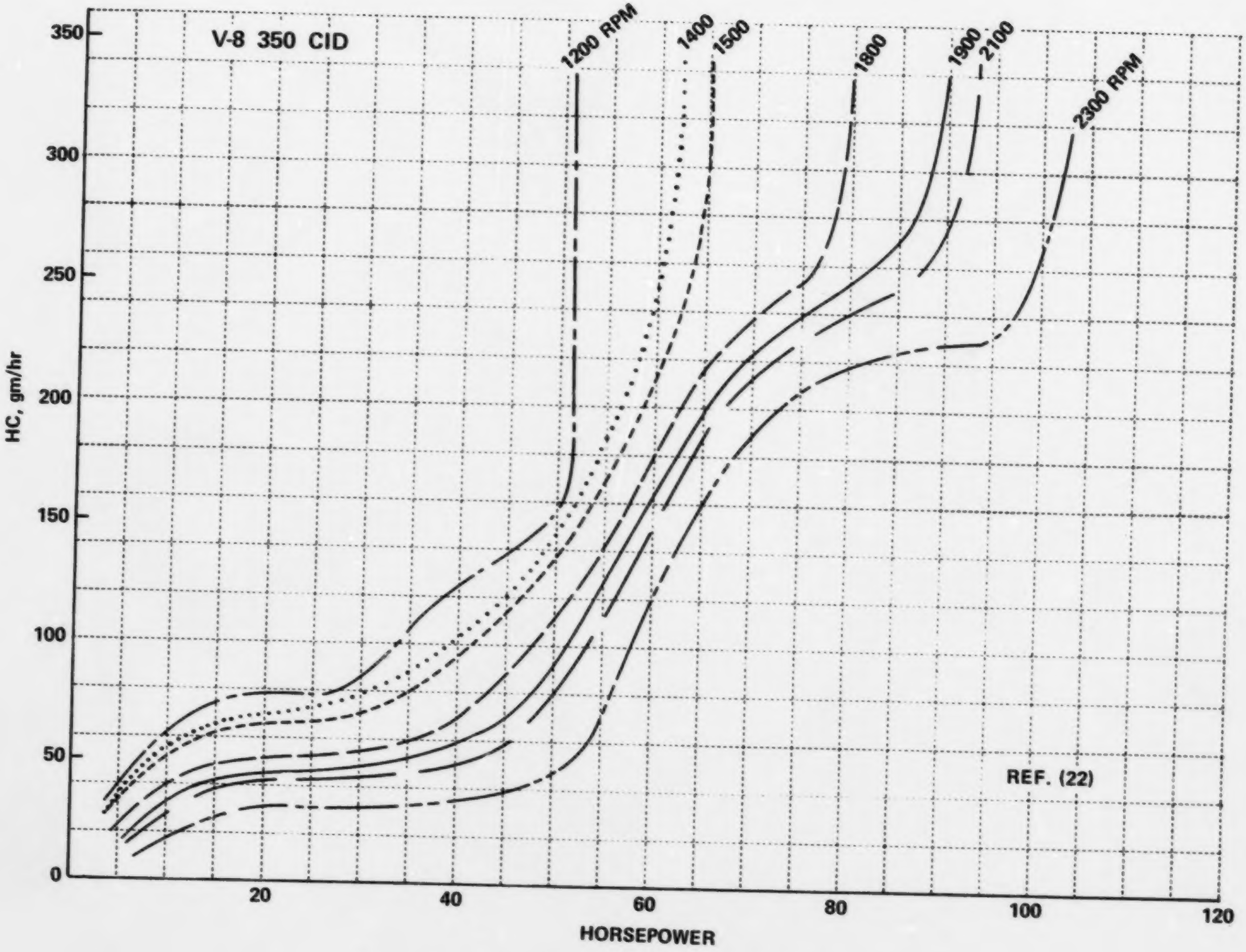

Figure A-7.2 HC ENGINE EMISSIONS (EXPERIMENTAL)

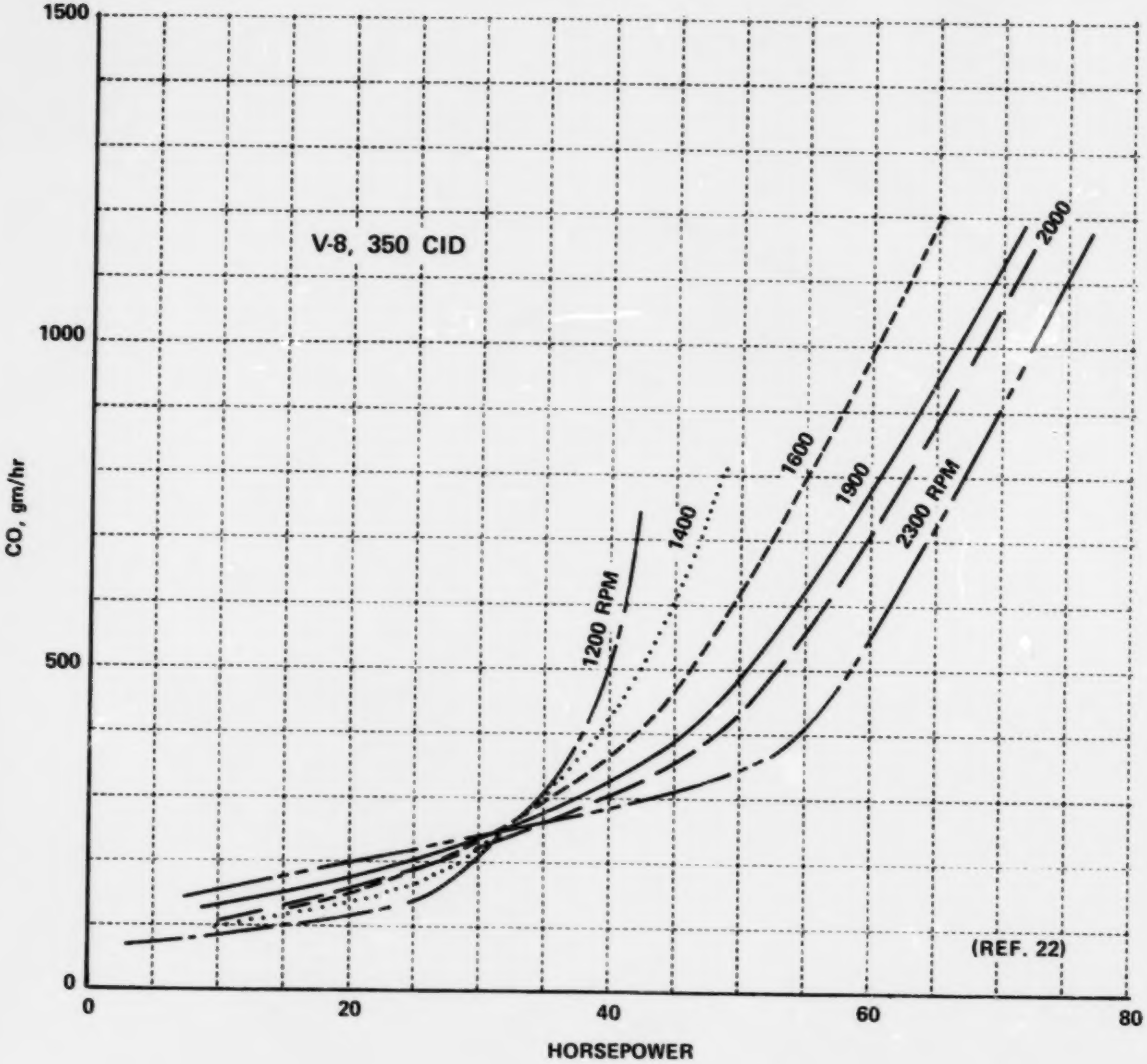

Figure A-7.3 CO ENGINE EMISSIONS (EXPERIMENTAL)

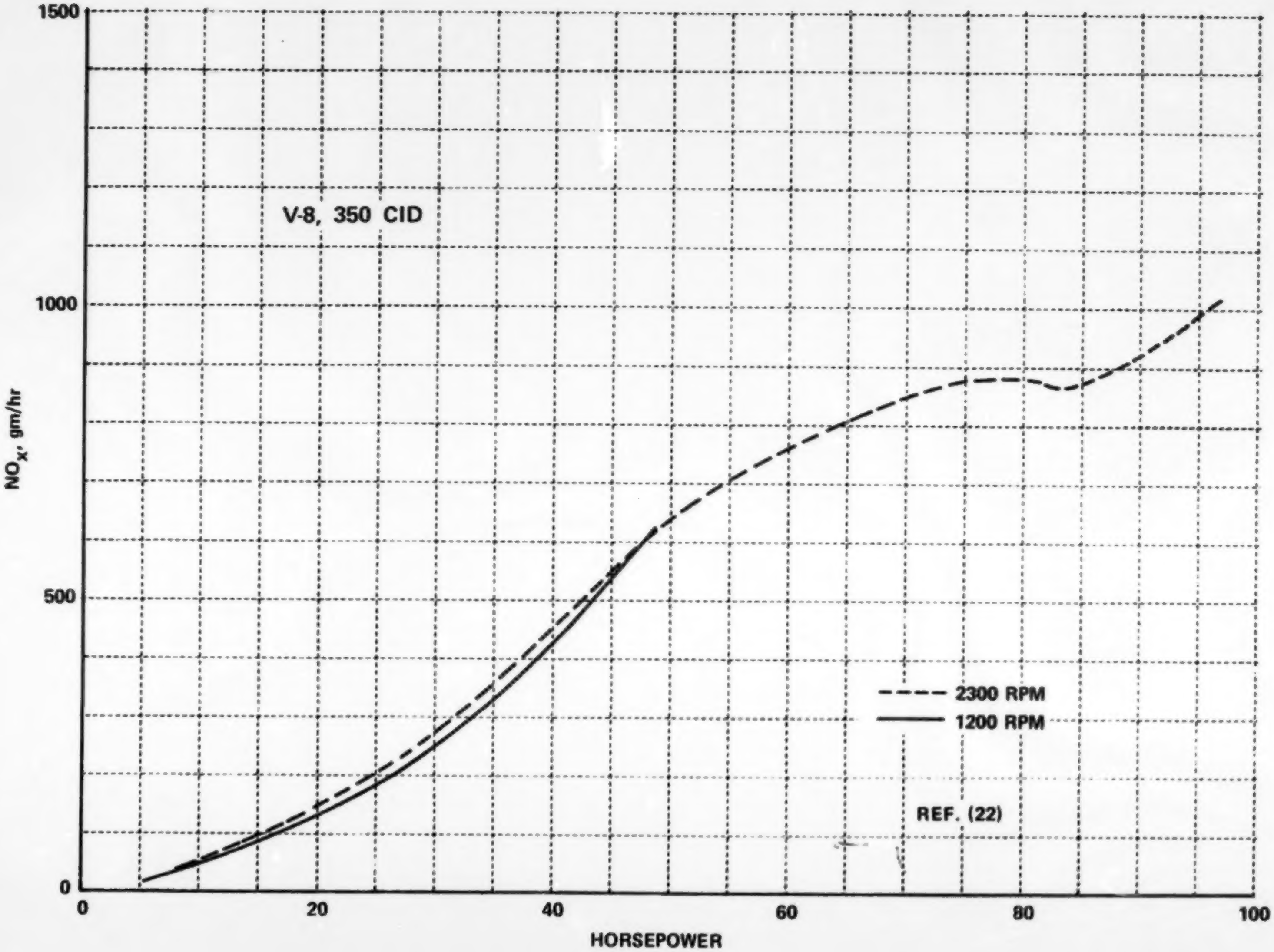

Figure A-7.4 NO$_x$ ENGINE EMISSIONS (EXPERIMENTAL)

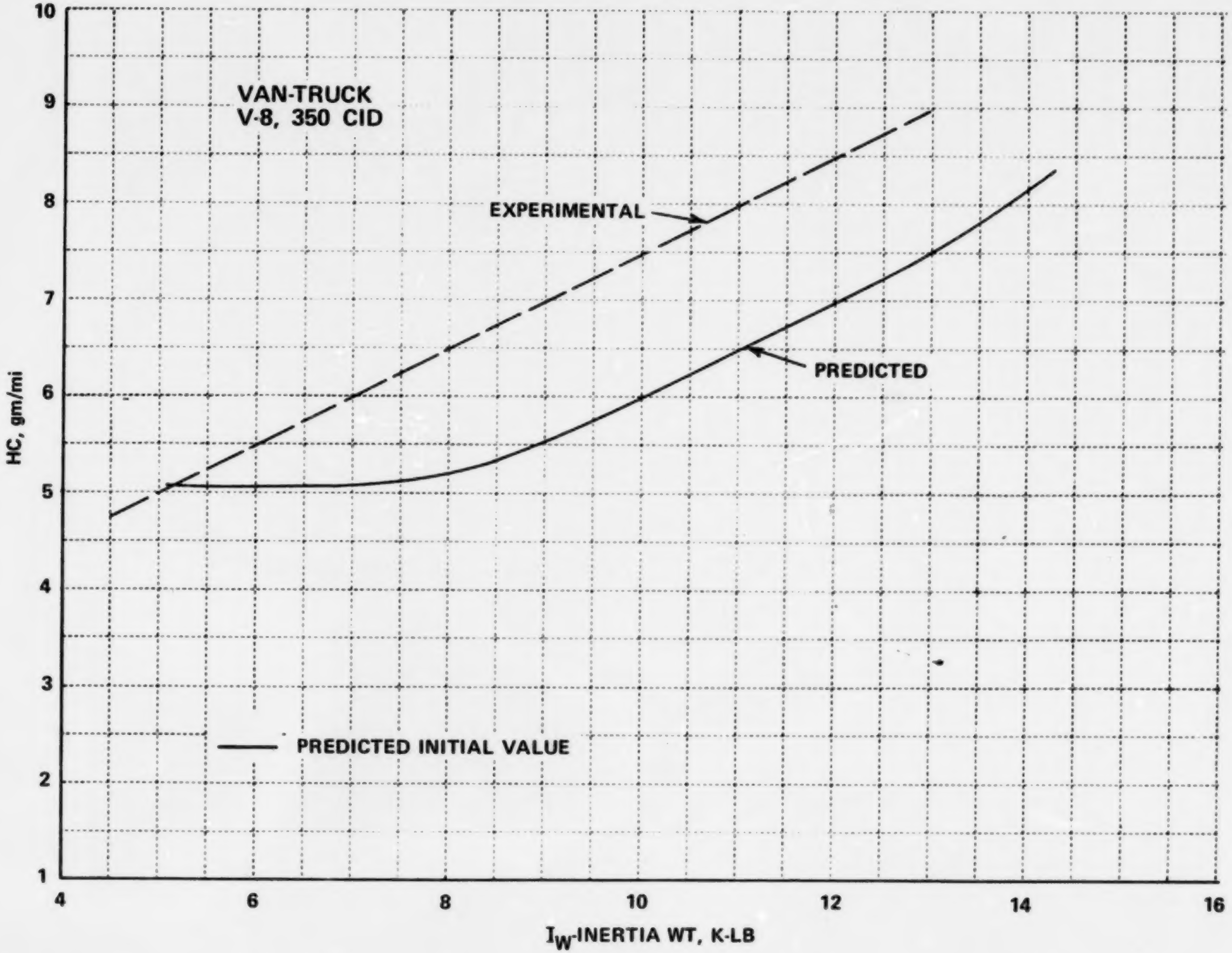

Figure A-7.5 COMPARISON OF PREDICTED AND MEASURED HC EMISSIONS AS A FUNCTION OF VEHICLE INERTIA WEIGHT

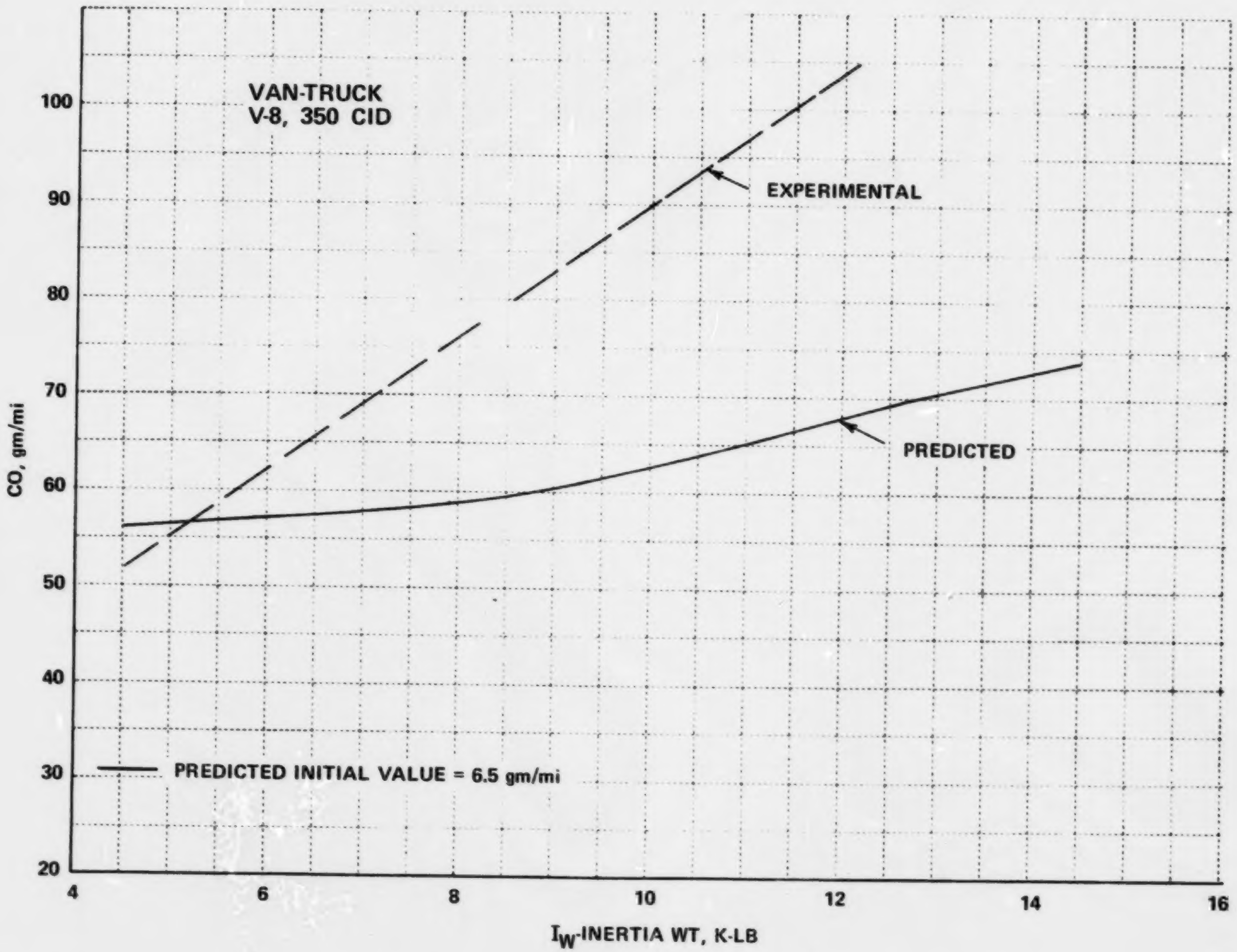

Figure A-7.6 COMPARISON OF PREDICTED AND MEASURED CO EMISSIONS AS A FUNCTION OF VEHICLE INERTIA WEIGHT

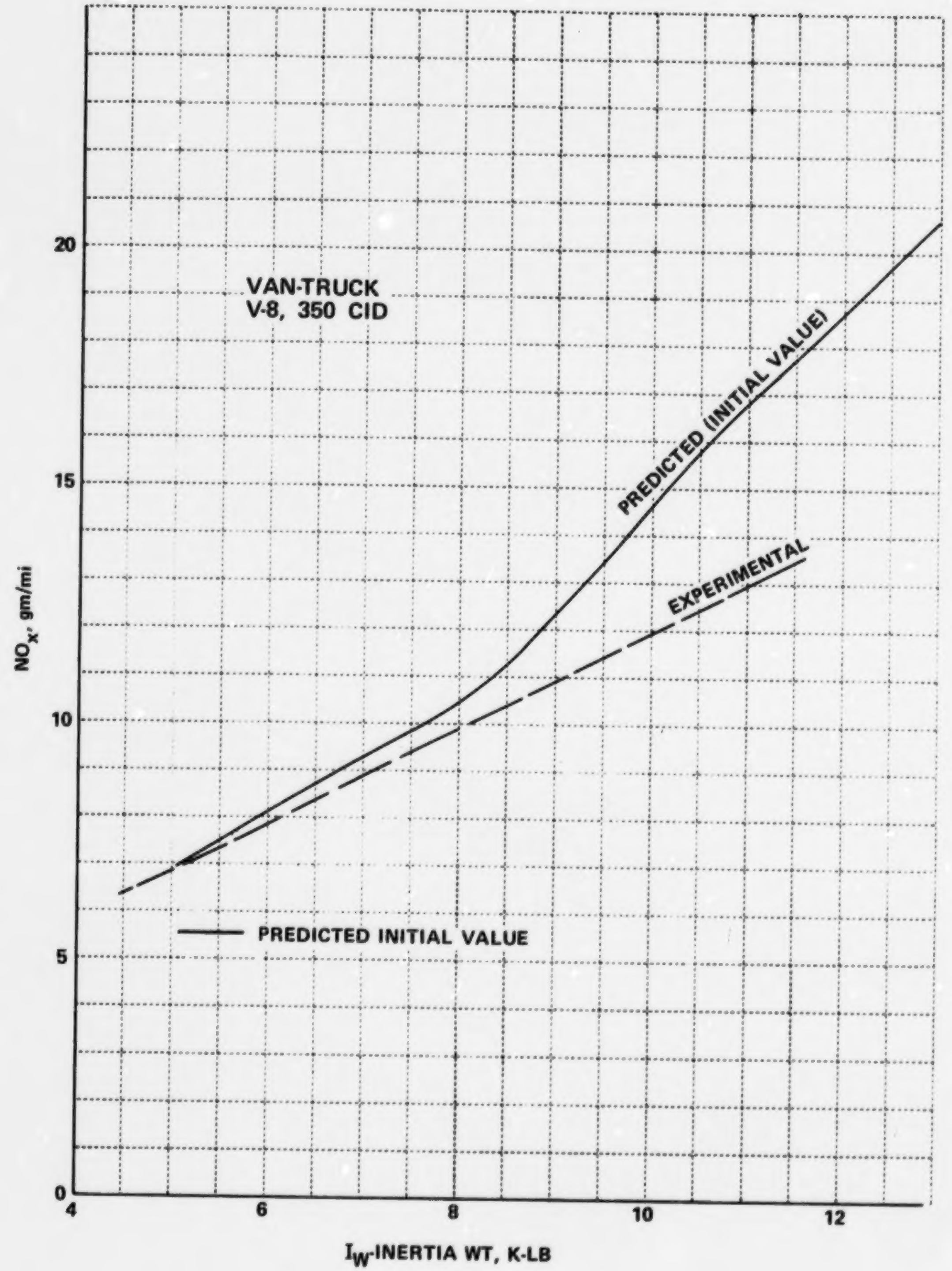

Figure A-7.7 COMPARISON OF PREDICTED AND MEASURED NO$_x$ EMISSIONS AS A FUNCTION OF VEHICLE INERTIA WEIGHT

APPENDIX A-8

DETAILED DESCRIPTION OF THE MEDIUM DUTY TRUCK EMISSIONS AND COST PROGRAM (AMTEC)

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As discussed in Section 2.7.3, a computer program (AMTEC) was written to analyze the costs and benefits of various control strategies for reducing medium duty truck emissions. In this appendix the computer program is described in detail and the input information used in typical calculations documented. A Fortran listing of the program is also included.

The medium duty truck population consists of vehicles of various ages, weights and shapes, engine types and emission control systems. For the purposes of calculation, the medium duty vehicles are divided into m categories (groups) with each group being delineated by weight/and or usage. In the present calculations, four groups (m = 4)

(1) 6,000 - 10,000 lb trucks
(2) 10,000 - 14,000 lb trucks
(3) 6,000 - 10,000 lb motor homes
(4) 10,000 - 14,000 lb motor homes

were considered. In order to further characterize vehicles within each group, it is necessary to specify the type of engine and, if any, the emission control system used. Type of engine designates general classes such as conventional gasoline, diesel, CVCC, etc. Differences in engine size (CID), if included in the vehicle characterization, would be accounted for by introducing additional vehicle groups. For example, 6,000 - 10,000 lb trucks with V-8, 360 CID engines and 6,000 - 10,000 lb trucks with V-8,

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454 CID engines would be treated as separate vehicle groups. Hence the program has the flexibility to consider different engines and sizes as well as different control systems.

The exhaust emissions can be expressed in terms of the baseline emissions for the vehicle/engine combination and the effectiveness of the control system used. Hence for the J^{th} pollutant (HC, CO, NO_x) the emissions (gm/mi) from a vehicle in group N can be written as

$$\text{TEM J (N, Yr I, k) RJ (k, i)}$$

where

TEM J (N, Yr I, k) ≡ emissions (gm/mi) of the J^{th} pollutant from a vehicle of group N of model year YrI having engine type k

R J (k, i) ≡ emission reduction factor for the J^{th} pollutant using the i^{th} control system on engine type k

The emissions of the J^{th} pollutant for all the vehicles of group N during the year Yr can be calculated by summing over the model years from 1950 to the year Yr. Thus

$$\text{emJ (N, Yr)} = K_1 \left\{ \sum_{YrI = 1950}^{Yr} \text{SALE (N, Yr I) FREM (N, Yr - Yr I)} \left[\sum_{k=1}^{m} \text{FRE (N, Yr I, k) TRAV (N, Yr - Yr I) TEMJ (N, Yr I, k) RJ (k, i)} \right] \right\}$$

where

SALE (N, YrI) $\equiv$ Sales of the N^{th} group of vehicles in the model year Yr I

FREM (N, Yr -Yr I) $\equiv$ Fraction of vehicles in group N remaining on the road after (Yr -Yr I) years

FRE (N, Yr I, k) $\equiv$ Fraction of sales of vehicles in group N in model year Yr I having engine type k

TRAV (N, Yr - Yr I) $\equiv$ miles traveled per year by vehicles in group N of age (Yr - Yr I)

K_1 = conversion factor for emissions in grams to emissions in tons.

The total emission of the J^{th} pollutant in the year Yr is then obtained by adding up the contributions of all the groups N. Thus

$$\text{EMTJ (Yr)} = \sum_{N=1}^{m} \text{emJ (N, Yr)}$$

where

EMTJ (Yr) $\equiv$ total emission of the J^{th} pollutant from all the medium duty vehicles on the road in year Yr.

m = number of vehicle groups considered.

The fuel consumed in the year Yr is computed for each vehicle group and engine type using the expression

$$\mathrm{KFUN}\,(N,\ Yr,\ k) = \sum_{YrI}^{Yr} \mathrm{SALE}\,(N, YrI)\,\mathrm{FREM}\,(N, Yr - YrI) \left[\frac{\mathrm{FRE}\,(N,\ YrI,\ k)\ \mathrm{TRAV}\,(N,\ Yr - Yr\,I)}{\mathrm{MPG}\,(N,\ k)}\right] * \left[1 + \mathrm{FP}\,(k,\ i)\right]$$

where

$\mathrm{KFUN}\,(N,\ Yr,\ k) \equiv$ fuel consumed by the vehicles in the N^{th} group in the year Yr having engine type k

$\mathrm{MPG}\,(N,\ k) =$ Fuel economy (miles per gallon) of vehicles in N^{th} group having engine type k

$\mathrm{FP}\,(k,\ i) \equiv$ Fuel penalty for the i^{th} control system used on engine type k

The total fuel consumed in year Yr by engines of type k is

$$\mathrm{KFU}\,(Yr,\ k) = \sum_{N=1}^{m} \mathrm{KFUN}\,(N,\ Yr,\ k)$$

The incremental fuel consumed by the engine type k due to the use of control systems and/or alternator engines is calculated from

$$\Delta \text{KFUN}(N, Yr, k) = \text{KFUN}(N, Yr, k)$$

$$\sum_{YrI}^{Yr} (\text{SALE})(\text{FREM})(\text{FRE}) \frac{\text{TRAV}}{\text{MPG}} (\text{FF}(k))$$

where

Δ KFUN (N, Yr, k) = incremental fuel consumed due to emission control by the vehicles in group N with engine type k

FF (k) = fuel factor relating baseline fuel economy of the alternate engine k and the conventional gasoline engine.

The incremental fuel consumed in year Yr by engines of type k is given by

$$\Delta \text{KFU}(Yr, k) = \sum_{N=1}^{m} \text{KFUN}(N, Yr, k)$$

where

Δ KFU (Yr, k) = incremental fuel consumed in the year Yr by engines of type k due to emission control strategies

The incremental costs associated with a specified emission control strategy, both the use of control systems and alternative engines, can be calculated from the following relation:

$$\mathrm{COST}\,(Yr) = \sum_{k=1}^{m} \Delta\,\mathrm{KFU}(Yr,\ k)\ \mathrm{GASCST}\,(k)$$

$$+ \sum_{N=1}^{m} \sum_{k=1}^{n} S(N,\ Yr)\ \mathrm{FRE}\,(N,\ Yr,\ k)\ \mathrm{IC}\,(k,i)$$

$$+ \sum_{N=1}^{m} \sum_{YrI=1950}^{Yr} \sum_{k=1}^{n} \Big[S\,(N,\ YrI)\ \mathrm{FREM}\,(N,\ Yr-YrI)\ \mathrm{FRE}\,(N, YrI, k)\ \mathrm{MC}\,(k,i) \Big]$$

where

COST (Yr) ≡ total incremental cost in the year Yr associated with emission reduction

GASCST(k) ≡ cost ($/gal) of the fuel for engines of type k

IC (k, i) ≡ incremental initial cost of engine type k with control system i

MC (k, i) ≡ incremental maintenance cost of engine type k with control system i

The maintenance cost MC is made up of two parts:

$$MC = (MC)_1 + (MC)_2$$

where

$(MC)_1$ = annual maintenance cost independent of mileage

$(MC)_2$ = catalyst maintenance cost dependent on mileage

Selected input data needed to obtain the results discussed in Section 2.7.4 are listed in the Tables A-8.1 with the sources for the data indicated. The remainder of the input data required is given elsewhere in the report as summarized in Table 2.24.

A typical output from the AMTEC program is shown in Table A-8.2. Graphical presentations of a series of computer runs (Table 2.25) are given in Figures 2.19-25.

```
              N=1             2              3              4
SALES  FOR  EACH  YEAR  BY  VEHICLE  TYPE
 1950    266000.       89000.             0.             0.
 1951    260000.       99000.             0.             0.
 1952    235000.       56000.             0.             0.
 1953    222000.       47000.             0.             0.
 1954    187000.       39000.             0.             0.
 1955    213000.       47000.             0.             0.
 1956    209000.       40000.             0.             0.
 1957    160000.       37000.             0.             0.
 1958    127000.       14000.             0.             0.
 1959    176000.       14000.             0.             0.
 1960    183000.       12000.             0.             0.
 1961    180000.       11000.             0.             0.
 1962    213000.        9000.             0.             0.
 1963    246000.        6000.             0.             0.
 1964    250000.        6000.             0.             0.
 1965    289000.        5000.          5000.             0.
 1966    292000.        8000.          6000.             0.
 1967    281000.        5000.          9000.             0.
 1968    373000.        5000.         13000.             0.
 1969    383000.        6000.         22000.          1000.
 1970    372000.        6000.         29000.          1000.
 1971    397000.        6000.         47000.         10000.
 1972    451000.        6000.         80000.         38000.
 1973    459000.        6000.         42000.         94000.
 1974    490000.        6000.         80000.         97000.
 1975    535000.        6000.         80000.        101000.
 1976    569000.        6000.         81000.        104000.
 1977    608000.        6000.         80000.        108000.
 1978    649000.        6000.         81000.        112000.
 1979    689000.        6000.         81000.        116000.
 1980    733000.        6000.         82000.        119000.
 1981    773000.        6000.         82000.        123000.
 1982    813000.        6000.         82000.        127000.
 1983    853000.        6000.         82000.        131000.
 1984    893000.        6000.         82000.        135000.
 1985    933000.        6000.         82000.        139000.
 1986    973000.        6000.         82000.        143000.
 1987   1013000.        6000.         82000.        147000.
 1988   1053000.        6000.         82000.        151000.
 1989   1093000.        6000.         82000.        155000.
```

TABLE A-8.1 Input Sales Data

FREM	
AGE	
1	0.994
2	0.974
3	0.961
4	0.940
5	0.909
6	0.872
7	0.838
8	0.791
9	0.745
10	0.686
11	0.625
12	0.558
13	0.487
14	0.403
15	0.325
16	0.243
17	0.163
18	0.080
19	0.0
20	0.0
21	0.0

Ref (36)

	TRAV			
	N=1	2	3	4
AGE				
1	11000.	11000.	5500.	5500.
2	10800.	10800.	5400.	5400.
3	10700.	10700.	5300.	5300.
4	10500.	10500.	5200.	5200.
5	10300.	10300.	5100.	5100.
6	10000.	10000.	5000.	5000.
7	9800.	9800.	4900.	4900.
8	9600.	9600.	4800.	4800.
9	9500.	9500.	4700.	4700.
10	9200.	9200.	4600.	4600.
11	9000.	9000.	4500.	4500.
12	8700.	8700.	4300.	4300.
13	8500.	8500.	4200.	4200.
14	8300.	8300.	4100.	4100.
15	8100.	8100.	4000.	4000.
16	7900.	7900.	3900.	3900.
17	7700.	7700.	3800.	3800.
18	7400.	7400.	3700.	3700.
19	7100.	7100.	3500.	3500.
20	6800.	6800.	3400.	3400.
21	6300.	6300.	3100.	3100.
22	5900.	5900.	2900.	2900.
23	5300.	5300.	2600.	2600.
24	4800.	4800.	2400.	2400.
25	4200.	4200.	2100.	2100.
26	3400.	3400.	1700.	1700.
27	2400.	2400.	1200.	1200.
28	0.	0.	0.	0.
29	0.	0.	0.	0.

Ref (37)

TABLE A-8.1 (cont) Input Vehicle Operation Data

Control System 0	1	2	3	4	5	6	7	8	9[(1)]	10[(2)]
THREE INITIAL COST LEVELS (ROW),LOW,NOMINAL,AND HIGH FOR EACH CONTROL SYSTEM (COL.)										
0.0	97.00	102.00	161.00	236.00	190.00	111.00	144.00	112.00	341.00	361.00
0.0	114.00	124.00	204.00	295.00	248.00	145.00	173.00	144.00	462.00	492.00
0.0	131.00	146.00	253.00	356.00	307.00	180.00	203.00	176.00	573.00	613.00
THREE LEVELS OF FIXED MAINTENANCE COST FOR EACH CONTROL SYSTEM										
0.0	3.00	3.00	8.00	8.00	3.00	3.00	3.00	3.00	3.00	3.00
0.0	3.00	3.00	8.00	8.00	3.00	3.00	3.00	3.00	3.00	3.00
0.0	3.00	3.00	8.00	8.00	3.00	3.00	3.00	3.00	3.00	3.00
THREE LEVELS OF VARIABLE(REPLACEMENT) MAINTENANCE COST FOR EACH CONTROL SYTEM. REPLACE EVERY25000. MILES										
0.0	22.50	22.50	105.00	222.50	121.50	12.50	22.50	22.50	0.0	0.0
0.0	22.50	22.50	130.00	272.50	146.50	12.50	22.50	22.50	0.0	0.0
0.0	22.50	22.50	152.50	317.50	169.00	12.50	22.50	22.50	0.0	0.0
THREE LEVELS OF VARIABLE(PARTIAL SUBSTITUTION) MAINTENANCE COST FOR EACH CONTROL SYSTEM. SUBSTITUTE EVERY25000. MILES										
0.0	22.50	22.50	85.00	175.00	101.50	12.50	22.50	22.50	0.0	0.0
0.0	22.50	22.50	102.50	210.00	119.00	12.50	22.50	22.50	0.0	0.0
0.0	22.50	22.50	120.00	245.00	136.50	12.50	22.50	22.50	0.0	0.0
THREE LEVELS OF VARIABLE(REPLACEMENT) MAINTENANCE COST FOR EACH CONTROL SYSTEM. REPLACE EVERY10000. MILES										
0.0	-8.00	-5.00	-5.00	-5.00	-8.00	-5.00	-8.00	1.00	0.0	4.00
0.0	-8.00	-5.00	-5.00	-5.00	-8.00	-5.00	-8.00	1.00	0.0	4.00
0.0	-8.00	-5.00	-5.00	-5.00	-8.00	-5.00	-8.00	1.00	0.0	4.00

(1) Baseline Diesel

(2) Diesel with EGR

TABLE A-8.1 (Cont.) Summary of Input Cost Data

```
          (1)          (1)          (1)          (2)          (2)          (2)          (2)          (3)          (3)          (3)
YEAR      HC           CO           NO           GAS        DEL GAS       DIESEL     DEL DIESEL    LOW COST        COST        HICOST
1970  0.4328E 06   0.4456E 07   0.2891E 06   0.3276E 10   0.0          0.0          0.0          0.0          0.0          0.0
1971  0.4221E 06   0.4432E 07   0.3083E 06   0.3460E 10   0.0          0.0          0.0          0.0          0.0          0.0
1972  0.4179E 06   0.4456E 07   0.3385E 06   0.3783E 10   0.0          0.0          0.0          0.0          0.0          0.0
1973  0.4191E 06   0.4525E 07   0.3742E 06   0.4108E 10   0.0          0.0          0.0          0.0          0.0          0.0
1974  0.4253E 06   0.4644E 07   0.4142E 06   0.4482E 10   0.0          0.0          0.0          0.0          0.0          0.0
1975  0.4176E 06   0.4540E 07   0.4279E 06   0.4926E 10   0.3698E 08   0.0          0.0          0.8790E 08   0.1055E 09   0.1234E 09
1976  0.4119E 06   0.4453E 07   0.4422E 06   0.5386E 10   0.7457E 08   0.0          0.0          0.1068E 09   0.1272E 09   0.1477E 09
1977  0.4074E 06   0.4370E 07   0.4565E 06   0.5861E 10   0.1135E 09   0.0          0.0          0.1265E 09   0.1499E 09   0.1732E 09
1978  0.3880E 06   0.4124E 07   0.4459E 06   0.6286E 10   0.1343E 09   0.3300E 08  -0.1677E 08   0.1573E 09   0.1951E 09   0.2324E 09
1979  0.3682E 06   0.3672E 07   0.4433E 06   0.6668E 10   0.1538E 09   0.1011E 09  -0.5141E 08   0.1597E 09   0.2134E 09   0.2560E 09
1980  0.3465E 06   0.3611E 07   0.4364E 06   0.6912E 10   0.1683E 09   0.2681E 09  -0.1363E 09   0.1838E 09   0.2400E 09   0.2937E 09
1981  0.3229E 06   0.3335E 07   0.4294E 06   0.7126E 10   0.1817E 09   0.4590E 09  -0.2333E 09   0.1682E 09   0.2267E 09   0.2822E 09
1982  0.2976E 06   0.3054E 07   0.4228E 06   0.7323E 10   0.1941E 09   0.6649E 09  -0.3380E 09   0.1444E 09   0.2028E 09   0.2580E 09
1983  0.2742E 06   0.2791E 07   0.4170E 06   0.7524E 10   0.2065E 09   0.8707E 09  -0.4426E 09   0.1158E 09   0.1723E 09   0.2253E 09
1984  0.2531E 06   0.2554E 07   0.4121E 06   0.7730E 10   0.2180E 09   0.1075E 10  -0.5465E 09   0.8713E 08   0.1417E 09   0.1926E 09
1985  0.2342E 06   0.2344E 07   0.4081E 06   0.7940E 10   0.2290E 09   0.1276E 10  -0.6487E 09   0.5891E 08   0.1115E 09   0.1605E 09
1986  0.2173E 06   0.2158E 07   0.4049E 06   0.8151E 10   0.2390E 09   0.1474E 10  -0.7495E 09   0.3084E 08   0.8157E 08   0.1285E 09
1987  0.2029E 06   0.2002E 07   0.4032E 06   0.8369E 10   0.2484E 09   0.1668E 10  -0.8478E 09   0.3517E 07   0.5246E 08   0.9746E 08
1988  0.1909E 06   0.1869E 07   0.4032E 06   0.8593E 10   0.2567E 09   0.1856E 10  -0.9436E 09  -0.2318E 08   0.2404E 08   0.6720E 08
1989  0.1807E 06   0.1763E 07   0.4048E 06   0.8823E 10   0.2646E 09   0.2037E 10  -0.1035E 10  -0.4853E 08  -0.2850E 07   0.3864E 08
```

(1) tons/year

(2) gal/year

(3) dollars/year

TABLE A-8.2 Typical Output From AMTEC Program

```
FORTRAN IV G LEVEL  21                 MAIN                DATE = 73151        14/15/42               PAGE 0001
              DATA GMPTON/907200.0/
              DATA THOUS/1000.0/
              REAL MPG(5,10)
              DIMENSION SALES(40,10),REMV(40),EM(4,5,10,40),FRE(40,5,10),
             *          TRAV(10,40),FRA(5,11,40),REMP(4,5,11),TEM(4,40),
             *          IND(10,40),RPLMC(3,11),SUBMC(3,11),FF(10),FUEL(5),
             *          FUPEN(11),TOC(3),TOTCST(3,40),OSTI(3,11),FIXMC(3,11),
             *          GASCST(3),DSLCST(3),COSTI(3,11),RPL10(3,11),JVD(10,40),
             *LEM(4)
         1000 FORMAT(8F10.0)
         1001 FORMAT(5I10)
         1002 FORMAT(I10,2F10.0)
         1003 FORMAT(4A4)
         1004 FORMAT(11F6.0)
              READ(5,1001) NCASE
              READ(5,1003)(LEM(L),L=1,4)
              READ (5,1001) NT,NE,NC
              READ(5,1001) IYR,JYR,LYR,IYRC,IYRD
              READ (5,1002) MCRS,DIST10,DIST25
              MYR=JYR-IYR+1
              NYR=LYR-IYR+1
              DO 2 JR=1,NYR
            2 READ(5,1000) (SALES(JR,IT),IT=1,NT)
              DU 92 JR=1,NYR
              DO 92 IT=1,NT
           92 SALES(JR,IT)=SALES(JR,IT)*THOUS
              WRITE(6,502)
          502 FORMAT(2X,'SALES FOR EACH YEAR BY VEHICLE TYPE')
              DO 902 JR=1,NYR
              KR=IYR+JR-1
          902 WRITE(6,4002) KR,(SALES(JR,IT),IT=1,NT)
         4002 FORMAT(2X,I5,10F10.0)
              JXRP=1
              JXR=IYRD-IYR
              IF(JXR.EQ.0) GU TO 703
              DO 933 JR=1,JXR
              DO 933 IT=1,NT
              FRE(JR,1,IT)=1.0
              DO 933 IE=2,NE
          933 FRE(JR,IE,IT)=0.0
              JXRP=JXR+1
          703 DO 3 JT=1,NT
              DO 3 JR=JXRP,NYR
            3 READ(5,1000) (FRE(JR,IE,JT),IE=1,NE)
              DU 803 IT=1,NT
              WRITE(6,503) IT
          503 FORMAT(2X,'DISTRIBUTION OF ENGINE TYPES BY MODEL YEAR FOR VEHICLES
             * OF TYPE',I3)
              DO 903 JR=1,NYR
              KR=IYR+JR-1
          903 WRITE(6,4003) KR,(FRE(JR,IE,IT),IE=1,NE)
         4003 FORMAT(2X,I5,10F6.2)
          803 CONTINUE
              DO 4 IE=1,NE
            4 READ (5,1000) (MPG(IE,IT),IT=1,NT)
              WRITE(6,504)
          504 FORMAT(2X,'GASOLINE CONSUMPTION (MPG) FOR EACH ENGINE (ROWS) AND F
             *OR EACH VEHICLE TYPE (COLS.)')
```

```
      DO 804 IE=1,NE
  804 WRITE(6,4004) (MPG(IE,IT),IT=1,NT)
 4004 FORMAT(2X,10F7.2)
      DO 5 JR=1,NYR
    5 READ(5,1000) (TRAV(IT,JR),IT=1,NT)
      DO 955 JR=1,NYR
      DO 955 IT=1,NT
  955 TRAV(IT,JR)=TRAV(IT,JR)*THOUS
      WRITE(6,505)
  505 FORMAT(2X,'MILES TRAVELED PER YEAR FOR EACH VEHICLE TYPE AS A FUNC
     *TION OF AGE',/,2X,' AGE ')
      DO 905 JR=1,NYR
  905 WRITE(6,4005) JR,(TRAV(IT,JR),IT=1,NT)
 4005 FORMAT(2X,I3,10F10.0)
      DO 6 L=1,3
      DO 6 IE=1,NE
      DO 6 JR=1,NYR
    6 READ(5,1000) (EM(L,IE,IT,JR),IT=1,NT)
      DO 906 L=1,3
      DO 806 IE=1,NE
      WRITE(6,506) LEM(L),IE
  506 FORMAT(2X,A4,'EMISSION (GMS/MILE) FROM ENGINES OF TYPE',I2,'WHEN U
     *SED ON VEHICLE TYPES (COLS.) BY MODEL YEAR')
      DO 706 JR=1,NYR
      KR=IYR+JR-1
  706 WRITE(6,4006) KR,(EM(L,IE,IT,JR),IT=1,NT)
 4006 FORMAT(2X,I5,10F6.1)
  806 CONTINUE
  906 CONTINUE
      READ(5,1000) (REMV(JR),JR=1,NYR)
      WRITE(6,507)
  507 FORMAT(2X,'FRACTION OF VEHICLES STILL OPERATING,AS A FUNCTION OF A
     *GE',/,2X,' AGE ')
      DO 907 JR=1,NYR
      WRITE(6,4007) JR, REMV(JR)
 4007 FORMAT(2X,I5,F7.3)
  907 CONTINUE
      DO 8 L=1,3
      DO 8 IC=1,NC
    8 READ(5,1000) (REMP(L,IE,IC),IE=1,NE)
      DO 908 L=1,3
      WRITE(6,508) LEM(L)
  508 FORMAT(2X,'REMAINING',A4,'EMISSION (FRACTION) WHEN USING CONTROL D
     *EVICE (ROW) ON EACH ENGINE TYPE (COLS.)')
      DO 808 IC=1,NC
  808 WRITE(6,4008) (REMP(L,IE,IC),IE=1,NE)
 4008 FORMAT(2X,10F8.2)
  908 CONTINUE
      DO 10 JJ=1,3
   10 READ(5,1000) (COSTI(JJ,IC),IC=1,NC)
      WRITE(6,510)
  510 FORMAT(2X,'THREE INITIAL COST LEVELS (ROW),LOW,NOMINAL,AND HIGH FO
     *R EACH CONTROL SYSTEM (COL.) ')
      DO 910 JJ=1,3
  910 WRITE(6,4010) (COSTI(JJ,IC),IC=1,NC)
 4010 FORMAT(2X,11F10.2)
      DO 11 JJ=1,3
   11 READ(5,1000) (FIXMC(JJ,IC),IC=1,NC)
```

```
      WRITE(6,511)
  511 FORMAT(2X,'THREE LEVELS OF FIXED MAINTENANCE COST FOR EACH CONTROL
     * SYSTEM')
      DO 911 JJ=1,3
  911 WRITE(6,4011) (FIXMC(JJ,IC),IC=1,NC)
 4011 FORMAT(2X,11F10.2)
      DO 12 JJ=1,3
   12 READ(5,1000) (RPLMC(JJ,IC),IC=1,NC)
      WRITE(6,512) DIST25
  512 FORMAT(2X,'THREE LEVELS OF VARIABLE(REPLACEMENT) MAINTENANCE COST
     *FOR EACH CONTROL SYTEM. REPLACE EVERY',F6.0,' MILES')
      DO 912 JJ=1,3
  912 WRITE(6,4012) (RPLMC(JJ,IC),IC=1,NC)
 4012 FORMAT(2X,11F10.2)
      DO 13 JJ=1,3
   13 READ(5,1000) (SUBMC(JJ,IC),IC=1,NC)
      WRITE(6,513) DIST25
  513 FORMAT(2X,'THREE LEVELS OF VARIABLE(PARTIAL SUBSTITUTION) MAINTENA
     *NCE COST FOR EACH CONTROL SYSTEM. SUBSTITUTE EVERY',F6.0,' MILES')
      DO 913 JJ=1,3
  913 WRITE(6,4013) (SUBMC(JJ,IC),IC=1,NC)
 4013 FORMAT(2X,11F10.2)
      DO 14 JJ=1,3
   14 READ (5,1000)(RPL10(JJ,IC),IC=1,NC)
      WRITE(6,514) DIST10
  514 FORMAT(2X,'THREE LEVELS OF VARIABLE(REPLACEMENT) MAINTENANCE COST
     *FOR EACH CONTROL SYSTEM. REPLACE EVERY',F6.0,' MILES')
      DO 914 JJ=1,3
  914 WRITE(6,4014) (RPL10(JJ,IC),IC=1,NC)
 4014 FORMAT(2X,11F10.2)
      READ(5,1000) (FUEL(IE),IE=1,NE)
      WRITE(6,4051)
 4051 FORMAT(2X,'FUEL TYPE BY ENGINE TYPE: 1=GASOLINE, 2=DIESEL')
      WRITE(6,951) (FUEL(IE),IE=1,NE)
  951 FORMAT(2X,5F10.0)
      READ(5,1000) (GASCST(JJ),JJ=1,3)
      WRITE(6,4052)
 4052 FORMAT(2X,'COST OF GASOLINE,DOLLARS PER GALLON',/,8X,'LOW',3X,'NOM
     *INAL',6X,'HIGH')
      WRITE(6,952) (GASCST(JJ),JJ=1,3)
  952 FORMAT(2X,3F10.2)
      READ(5,1000) (DSLCST(JJ),JJ=1,3)
      WRITE(6,4053)
 4053 FORMAT(2X,'COST OF DIESEL FUEL,DOLLARS PER GALLON',/,8X,'LOW',3X,'
     *NOMINAL',6X,'HIGH')
      WRITE(6,953) (DSLCST(JJ),JJ=1,3)
  953 FORMAT(2X,3F10.2)
      READ(5,1000) (FUPEN(IC),IC=1,NC)
      WRITE(6,4054)
 4054 FORMAT(2X,'FUEL PENALTY (GAIN,IF NEGATIVE) FOR USING EACH CONTROL
     *SYSTEM')
      WRITE(6,954) (FUPEN(IC),IC=1,NC)
  954 FORMAT(2X,11F6.2)
      READ(5,1000) (FF(IE),IE=1,NE)
      WRITE(6,4055)
 4055 FORMAT(2X,'FUEL ADJUSTMENT FACTORS BY VEHICLE TYPE')
      WRITE(6,1955) (FF(IE),IE=1,NE)
 1955 FORMAT(2X,10F6.2)
```

```
               WRITE(6,520)
           520 FORMAT(2X,'VEHICLE POPULATION BY YEAR')
               DO 20 JR=1,NYR
               ONROAD=0.0
               JXRZ=IYR+JR-1
               DO 19 IT=1,NT
               DO 19 J=1,JR
               IAGE=JR-J+1
            19 ONROAD=ONROAD+SALES(J,IT)*REMV(IAGE)
               ONROAD=ONROAD/THOUS
               WRITE(6,4020) JXRZ,ONROAD
          4020 FORMAT(2X,I10,F10.0)
            20 CONTINUE
               DO 26 IT=1,NT
               D=0.0
               DD=0.0
               DO 25 IAGE=1,NYR
               D=D+TRAV(IT,IAGE)
               DD=DD+TRAV(IT,IAGE)
               J=D/DIST25
               K=DD/DIST10
               IF(J.EQ.0) GO TO 22
               IND(IT,IAGE)=1
               D=D-J*DIST25
               GO TO 23
            22 IND(IT,IAGE)=0
            23 IF(K.EQ.0) GO TO 24
               JND(IT,IAGE)=1
               DD=DD-K*DIST10
               GO TO 25
            24 JND(IT,IAGE)=0
            25 CONTINUE
            26 CONTINUE
               DO 410 JCASE=1,NCASE
               JXS=1
               JXR=IYRC-IYR
               IF(JXR.EQ.0) GO TO 709
               DO 99 JR=1,JXR
               DO 99 IE=1,NE
               FRA(IE,1,JR)=1.0
               DO 99 IC=2,NC
            99 FRA(IE,IC,JR)=0.0
               JXS=JXR+1
           709 DO 9 JR=JXS,NYR
               DO 9 IE=1,NE
             9 READ (5,1004) (FRA(IE,IC,JR),IC=1,NC)
               DO 909 JR=1,NYR
               KR=IYR+JR-1
               WRITE(6,509) KR
           509 FORMAT(2X,'FRACTION OF ENGINES (ROWS) EQUIPPED WITH TYPES OF POLLU
              *TION CONTROL DEVICES (COLS.) FOR MODEL YEAR',I5)
               DO 809 IE=1,NE
           809 WRITE(6,4009) (FRA(IE,IC,JR),IC=1,NC)
          4009 FORMAT(2X,11F6.2)
           909 CONTINUE
               WRITE(6,2000) (LEM(L),L=1,3)
          2000 FORMAT(1X,'YEAR',3(4X,A4,4X),          5X,'GAS',6X,'DEL GAS'
              *,6X,'DIESEL',4X,'DEL DIESEL',4X,'LOW COST',5X,'COST',8X,'HICOST')
```

```
0212               DO 400 JR=MYR,NYR
0213               DO 70 L=1,3
0214               SUMIC=0.0
0215               DO 60 IC=1,NC
0216               SUMIE=0.0
0217               DO 50 IE=1,NE
0218               SUMJR=0.0
0219               DO 40 J=1,JR
0220               IAGE=JR-J+1
0221               SUMIT=0.0
0222               DO 30 IT=1,NT
0223            30 SUMIT=SUMIT+SALES(J,IT)*REMV(IAGE)    *EM(L,IE,IT,J)*TRAV(IT,IAGE)
0224            40 SUMJR=SUMJR+SUMIT*FRA(IE,IC,J)
                  **FRE(J,IE,IT)
0225            50 SUMIE=SUMIE+REMP(L,IE,IC)*SUMJR
0226            60 SUMIC=SUMIC+SUMIE
0227            70 TEM(L,JR)=SUMIC/GMPTON
0228            80 CONTINUE
0229               FUG=0.0
0230               FUD=0.0
0231               DFUG=0.0
0232               DFUD=0.0
0233               DO 130 IE=1,NE
0234               JF=FUEL(IE)
0235               SUMITA=0.0
0236               SUMITB=).0
0237               DO 120 IT=1,NT
0238               SUMJA=0.0
0239               SUMJB=0.0
0240               DO 110 J=1,JR
0241               IAGE=JR-J+1
0242               A=SALES(J,IT)*REMV(IAGE)*FRE(J,IE,IT)*TRAV(IT,IAGE)/MPG(IE,IT)
0243               SUMICA=0.0
0244               SUMICB=0.0
0245               DO 100 IC=1,NC
0246               SUMICA=SUMICA+A*FRA(IE,IC,J)*(1.0+FUPEN(IC))
0247           100 SUMICB=SUMICB+A*FRA(IE,IC,J)/FF(IE)
0248               SUMJA=SUMJA+SUMICA
0249           110 SUMJB=SUMJB+SUMICB
0250               SUMITA=SUMITA+SUMJA
0251           120 SUMITB=SUMITB+SUMJB
0252               GO TO (124,126),JF
0253           124 FUG=FUG+SUMITA
0254               DFUG=DFUG+SUMITB
0255               GO TO 130
0256           126 FUD=FUD+SUMITA
0257               DFUD=DFUD+SUMITB
0258           130 CONTINUE
0259               DFUG=FUG-DFUG
0260               DFUD=FUD-DFUD
0261               DO 350 JJ=1,3
0262               DO 150 J=1,3
0263           150 TOC(J)=0.0
0264               DO 230 IC=1,NC
0265               SUMIE=0.0
0266               DO 220 IE=1,NE
0267               SUMIT=0.0
0268               DO 210 IT=1,NT
```

```
      J=JR
      SUMJ=SALES(J,IT)*FRE(J,IE,IT)*FRA(IE,IC,J)
  210 SUMIT=SUMIT+SUMJ
  220 SUMIE=SUMIE+SUMIT
      OSTI(JJ,IC)=SUMIE*COSTI(JJ,IC)
  230 TOC(JJ)=TOC(JJ)+OSTI(JJ,IC)
      DU 330 J=1,JR
      IAGE=JR-J+1
      SUMIC=0.0
      DO 320 IC=1,NC
      SUMIT=0.0
      DO 310 IT=1,NT
      SUMIE=0.0
      UO 300 IE=1,NE
  300 SUMIE=SUMIE+SALES(J,IT)*FRE(J,IE,IT)*FRA(IE,IC,J)*REMV(IAGE)
      A=FIXMC(JJ,IC)+IND(IT,IAGE)*(RPLMC(JJ,IC)*MCRS+SUBMC(JJ,IC)*
     *(1-MCRS))+JND(IT,IAGE)*RPL10(JJ,IC)
  310 SUMIT=SUMIT+SUMIE*A
  320 SUMIC=SUMIC+SUMIT
  330 TOTCST(JJ,JR)=DFUG*GASCST(JJ)+DFUD*DSLCST(JJ)+TOC(JJ)+SJMIC
  350 CONTINUE
      JX=JR-1+IYR
      WRITE(6,2001) JX,(TEM(L,JR),L=1,3),FUG,DFUG,FUD,DFUD,(T3TCST(JJ,JR
     *),JJ=1,3)
 2001 FORMAT(1X,I4,10E12.4)
  400 CONTINUE
  410 CONTINUE
      STOP
      END
```

APPENDIX A-9

GRAPHICAL SUMMARY OF BASELINE EMISSIONS DATA VERSUS INERTIA WEIGHT

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MDV BASELINE HC EMISSIONS vs INERTIA WEIGHT
(MEASURED ON MODIFIED 1975 LDV FTP)

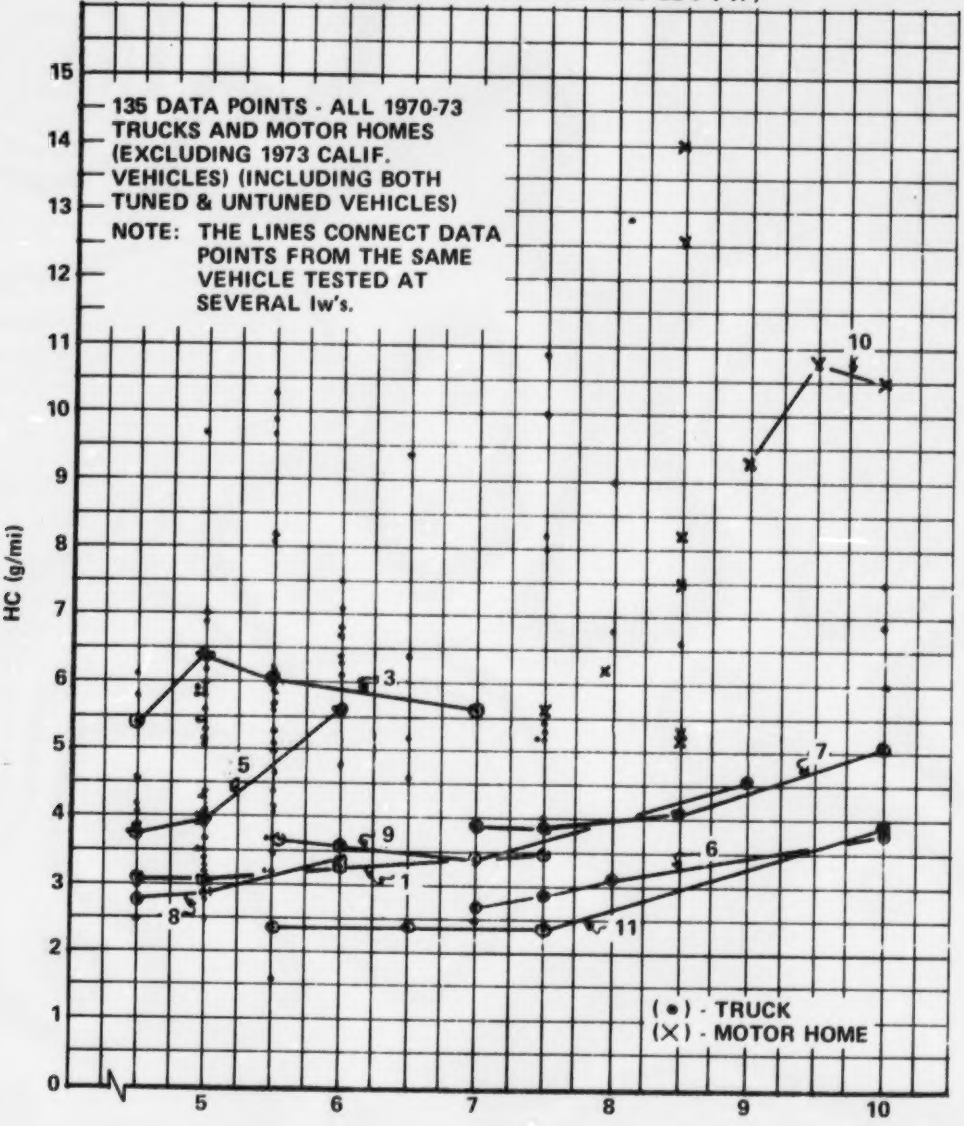

Figure A-9.1 INERTIA WEIGHT (1000 LBS)

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MDV BASELINE CO EMISSIONS vs INERTIA WEIGHT
(MEASURED ON MODIFIED 1975 LDV FTP)

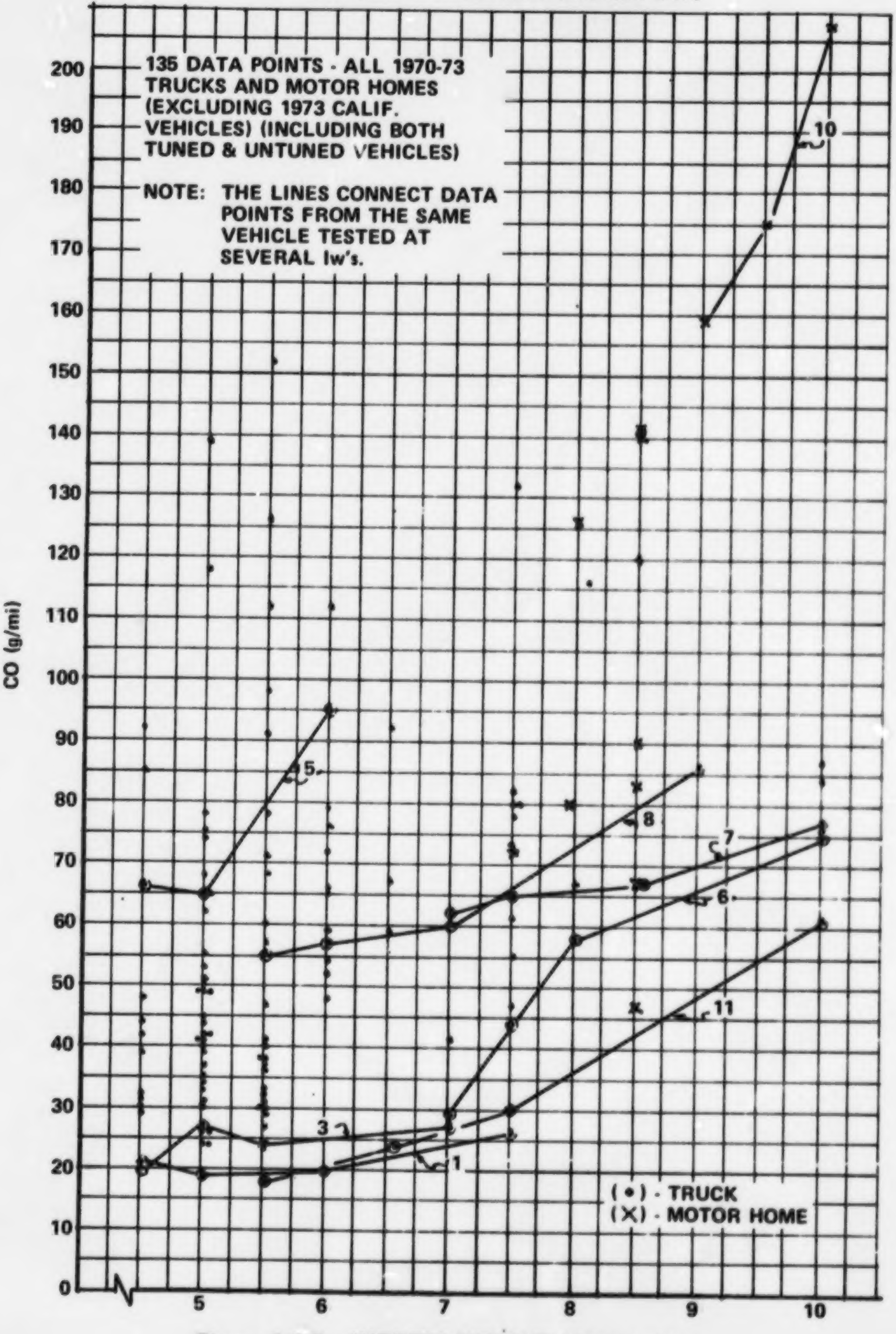


Figure A-9.2 INERTIA WEIGHT (1000 LBS)

MDV BASELINE NO_x EMISSIONS vs INERTIA WEIGHT
(MEASURED ON MODIFIED 1975 LDV FTP)

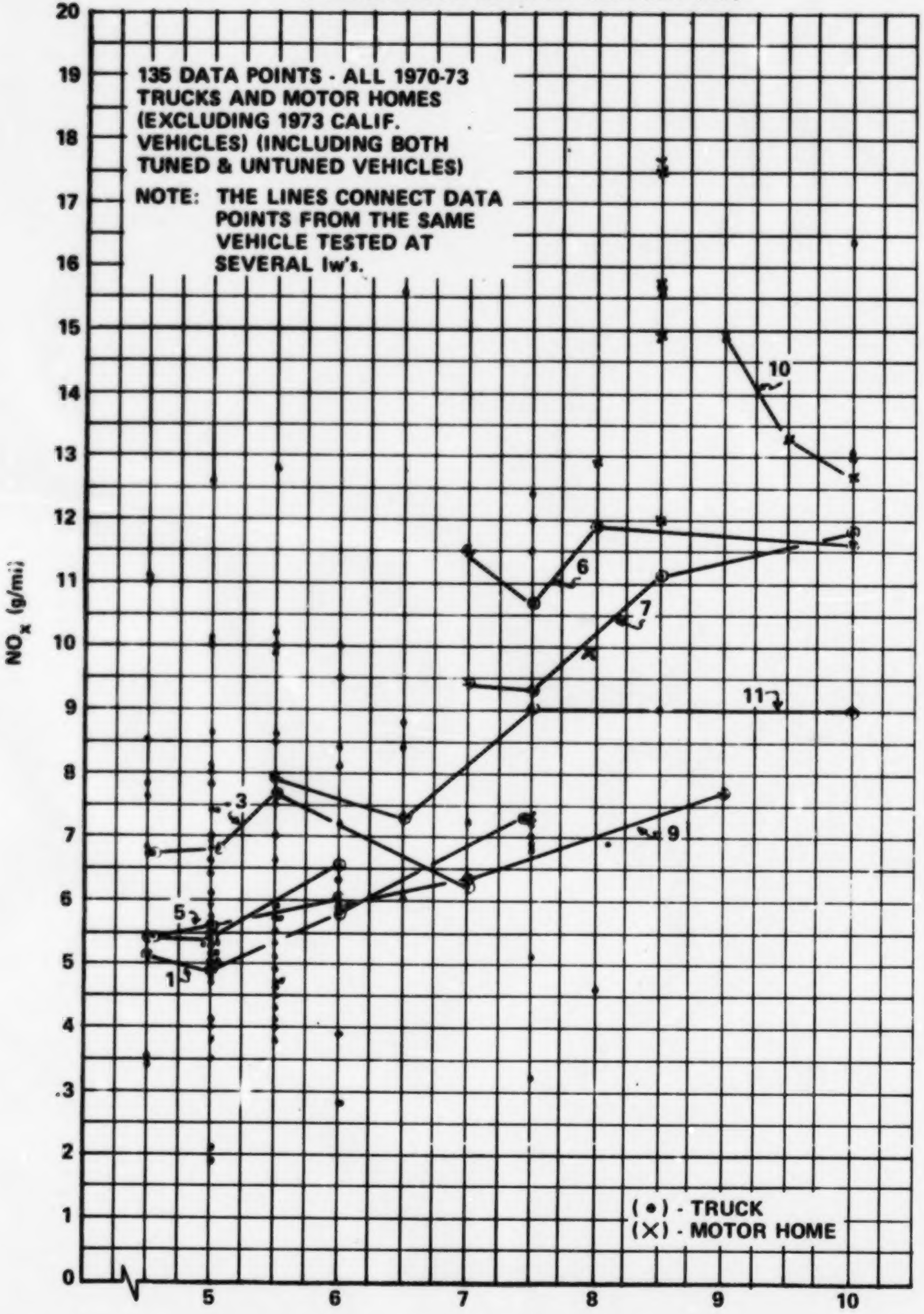


Figure A-9-3 INERTIA WEIGHT (1000 LBS)

APPENDIX B-1

Catalytic Converter Cost and Production Lead Time

Introduction and Summary

Schedules submitted to the EPA and Aerospace Corporation by catalyst and substrate suppliers are shown in Figure B.1. The operations considered in estimating the lead times are design, engineering, construction of new facilities, installation of equipment, and production build up.

The corresponding sets of data from the catalyst and substrate suppliers are found to be in agreement. It can readily be seen that the lead times estimated to be required by the various substrate suppliers vary in a range from 12 to 24 months while catalyst suppliers vary from 20 to 24 months. The differences in lead time may be due to varying degrees of optimism in estimating the facility construction and equipment schedule. From Figure B.1, and allowing for the fact that production catalysts must be available at the manufacturers plant in advance of first vehicle production, the automotive manufacturer lead time requirement would be expected to be approximately 2 years.

In general, the agreement in catalytic converter production milestones among various automotive manufacturers is good. Among all the automotive manufacturers represented the overall lead time requirement ranges from 24 to 28 months. This is due primarily to the fact that the converter represents a new technology, and involves a source of supply that the automotive industry is unfamiliar with in high-volume production. Thus, the lead time requirement includes the uncertainties associated with new vendor associations. The overall production lead time schedules for the major automobile manufacturers are shown in Figure B.2. It could be concluded that there are no gross inconsistencies among or between the lead time specifications of the suppliers and manufacturers.

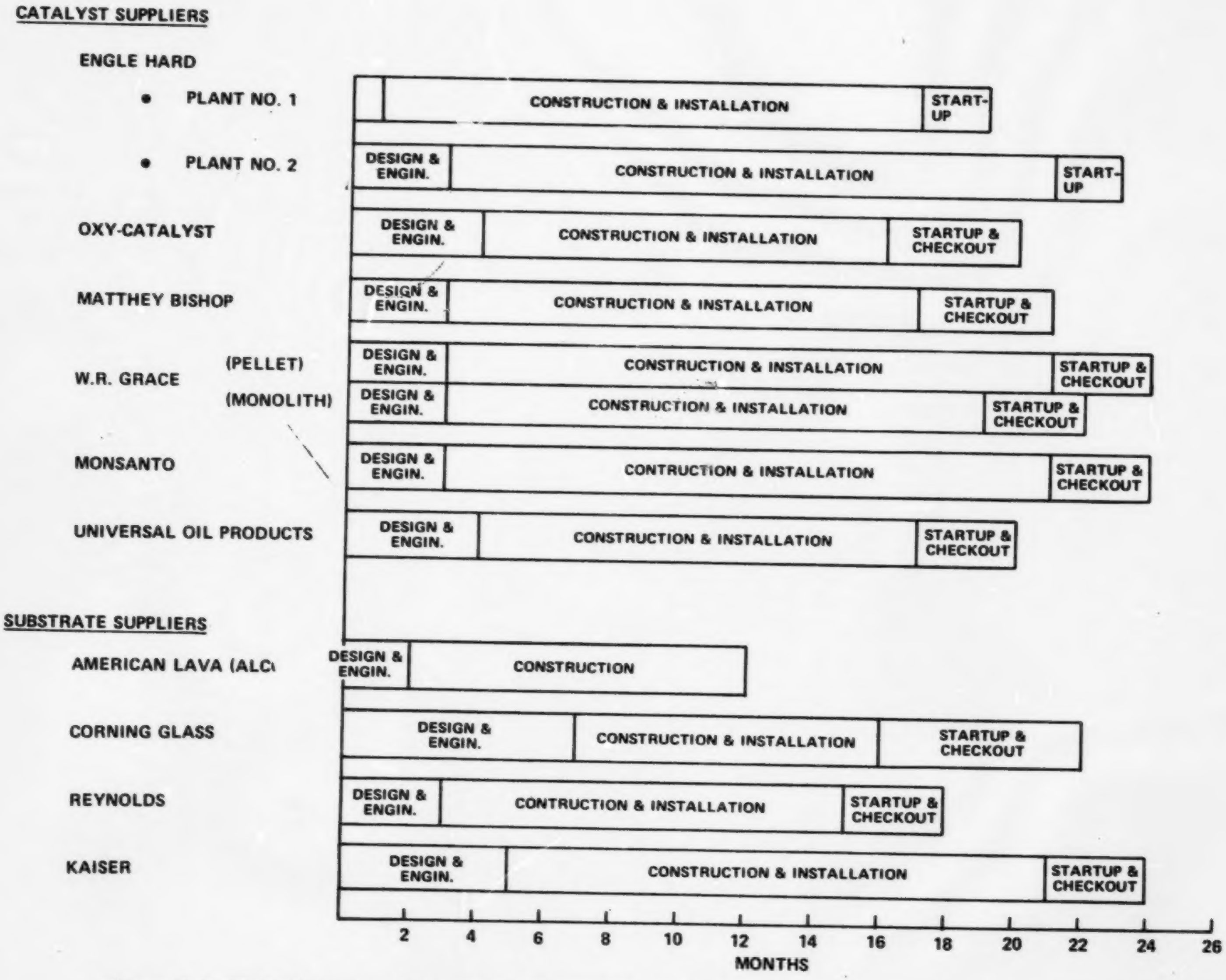
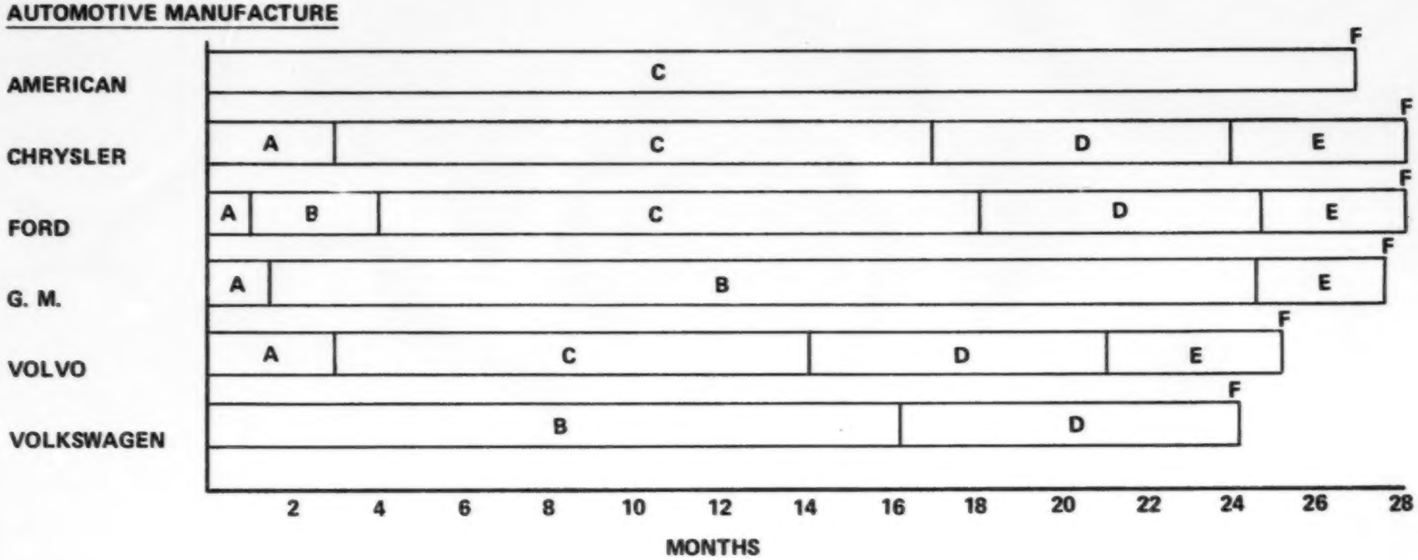


Figure B.1 PRODUCTION LEAD TIME SCHEDULES FOR CATALYST AND SUBSTRATE SUPPLIERS



A - PRODUCTION DESIGN & PRELIMINARY APPROVAL

B - TOOLING AND FACILITIES PROGRAM APPROVAL

C - FACILITIES AND LONG LEAD TIME PARTS/EQUIPMENT

D - DURABILITY AND CERTIFICATION TESTS

E - VEHICLE PILOT PART PROGRAM

F - START VEHICLE PRODUCTION

Figure B.2 PRODUCTION LEAD TIME SCHEDULES FOR CATALYTIC CONVERTERS (DATA SUPPLIED BY AUTOMOBILE MANUFACTURERS)

One of the most pressing issues concerning catalytic converters is the use and supply of noble metals. Those considered are platinum and palladium at a cost of $130/troy ounce and $40/troy ounce respectively. The estimated usage of platinum per converter runs anywhere from 0.03-0.1 troy ounce, i.e. a cost of $4-$13. The final price of a complete converter package may range from $10 to $50 for light duty vehicles. This price would depend on many factors; the amount of noble metal used, substrate, and the final configuration of the converter.

To date Ford Motor Company is the only automotive manufacturer that has made a commitment to a catalyst supplier. Their contract with Engelhard Industry for supplying catalyst has provided financial backing of up to $4.9 million for facilities and equipment. Ford also has made purchase commitments with American Lava. The lead time for the development of these supplier facilities is about 24 months.

Discussion

Catalytic converters primarily consist of a catalytic material such as a base or noble metal or some combination of the two. Noble metals seem to be the choice since performance is much better although the cost is considerably higher. The noble metals being considered are platinum and palladium which are applied on an inert support material (substrate) either chemically or mechanically. The support consists of alumina in the form of pellets or a honeycomb mononithic structure. Almost all monoliths being considered are composed of material such that the noble metal will not adhere. Thus, it must be coated (washed) with Al_2O_3. The catalyst coated substrate is then canned in a stainless steel casing and placed in the exhaust system so that the exhaust flow is directed through the catalyst bed.

As of now there is no single producer of a complete catalytic converter package. At most there exist a few firms which will make their own substrate and plate it with the necessary noble or base metal catalyst but even these firms will not produce canisters or can the product. Thus, in estimating the lead time and cost to the auto manufacturer and consumer each component of the converter must be considered separately.

Generally the substrate is produced by one manufacturer; it is then passed onto a catalyst manufacturer who plates the substrate who in turn passes the finished catalyst to the auto company. Some auto firms are planning to do their own cannister production while others are seeking cannister producers.

Before considering the cost of the catalytic material and its applications the type of substrate to be used must first be resolved. Basically the substrate considered is of two types, pellet or beads and monolithic. Each have different characteristics as to cost, performance, durability and replacement.

Pellets, in general, are considerably cheaper and replacement is a much simpler process. The raw material for alumina pellet support is very plentiful. Reynolds has stated that they alone could supply the entire automotive industry with alumina support for 20 years without a dent in their reserves. Their current production is several hundred thousand tons per year with present facilities. However, in order to supply the auto industries Reynolds says that additional production facilities would have to be constructed, and that such an undertaking would require at least a 3 year committment to purchase from auto manufacturers.

The plant, which solely produces alumina support, would require a total lead time of about 18 months before full production is under way with preliminary engineering and construction taking 3 and 12 months respectively. Approximately 3 additional months would be needed for plant start-up and check out. With such a plant operating at full capacity they could supply 14 mil pounds per year at a cost of $0.41/lb. F.O.B. This will supply enough support material for about 2,000,000 converters based on an estimate of 5-6 lbs. per converter. Capital investment would run $4-5 million.

Kaiser Chemicals is also considering productions of alumina pellet substrate, however not much information is available. They have spent over $1 million of their own money without getting any contracts to supply. Should an agreement be made with any auto or catalyst manufacturer, a new plant would be required. It would take approximately 24 months to get full production out of the plant. Twenty-one months will be needed for engineering, design and construction and an additional 3 months start-up.

Monoliths considered fall into two basic designs, round and oval. All but one auto firm prefer round which has been quoted as being cheaper by a factor of up to 2.

Some producers namely American Lava Company, hereafter called Alco, and Corning Glass have spent considerable time and money developing monolithic substrates for converters.

Alco, a subsidiary company of 3M, has contacted all domestic auto manufacturing and catalyst suppliers but as yet (9/1/72) has not made any contractual agreement to supply catalytic substrate. They have made an agreement with Ford in June '72 for the scale up of production facilities to meet a portion of Ford's substrate requirements for 1975 model vehicles. This agreement guarantees that if Ford should cancel their order they would reimburse Alco for all non-recoverable expenditures.

Alco's production capabilities are in discrete production units called "modules" with each module having the capacity to produce 1.5 million units per year under a normal 2 shift, 5 day week basis. This could be increased to 2.25 million units using 3 shifts. Two such units are presently covered by a contract with Ford. The first, started in Jan. '72 is still under construction and due to be completed in the first quarter of '73. The second is in the planning stage and will not be completed until the 1st quarter of '74. These two modules alone could supply all of Ford's needs for 1975. Additional modules would be required to supply other auto manufacturers.

With their present Chattanooga plant, Alco would set up 4 such modules with a capacity of 6-9 million units and only a warehouse would be needed for raw material storage. This is the only critical lead time item mentioned. Construction must be started by 10/72 to meet their planned schedule of completion in Sept. '73. Should demand increase, additional modules could be installed in other 3M plants located outside Chattanooga.

According to Alco's Manufacturing Scale-up for Substrates, they could reach a production level of 4.5 million units a year by July '73, only 18 months after program initiation of Jan. '72. Thus, Ford's requirements of 3 million units a year could be met in considerably less time than the present agreement schedule provides. Twenty-six months is the indicated requirement for the Alco goal of 9 million units by March, 1974. Alco claims that March '73 was the latest they could accept on order from General Motors to build substrate in quantity. This suggests that Alco could double the number of Modules from 2 to 4 in a matter of 12 months. They also claim that by March '75 production could reach 30 million units a year and no new construction of a plant would be needed. Should orders exceed this amount, new facilities would then be needed.

Basic component values were quoted at $5 for the ceramic substrate and $8 for the platinum. However, Matthey-Bishop, a catalyst manufacturer, has received cost quotes from Alco of $2.81 per round substrates and almost double for oval configurations. It is Alco's estimate that a complete monolithic converter should cost no more than $40-$50 for light duty vehicles.

Corning Glass is considering supplying only monolith substrate. As yet they have not made any contractual committments with catalyst platers or auto manufacturers. They are currently operating a pilot production facility with a monthly output of 1500-3000 units. With added equipment, they expect a production capacity of 30,000 or more per month by June '73. There seems to be no lead time problem with vendor-parts. Also, raw materials are available at any time in carload lots. Cost for round configurations is estimated to be $2.54 per unit and slightly higher for oval.

A number of catalyst manufacturers have already been contacted by auto firms. Monsanto has originally only considered a pellet type base metal catalyst but has since then been encouraged to use noble metal as well. They have no plans to manufacture substrate or canisters. The substrate would be purchased from Kaiser and/or Reynolds and canister production would be handled by auto manufacturers themselves. They foresee no difficulties in acquiring noble metal. Monsanto has established good relations with Russia and has already requested permission from the State Department to investigate a noble metal deal with them.

Monsanto has no existing facilities that could be modified for catalyst production. Thus, construction of a new plant would be needed but a firm commitment to purchase would be required before any detail design and construction is started. The anticipated production would be 10-50 mil pounds of plated substrate per year enough for 2-10 mil converters.

Since this would be a major undertaking for Monsanto the total estimated expenditure is of the order of several million dollars. They have indicated that a lead time of 24 months from the date of site selection until full production is under way. Site evaluation, design and construction would take 21 months with an additional 3 months needed for plant checkout and start-up. This lead time schedule is in reasonable agreement with Reynolds and Kaiser. Also, it is compatible with the 18 month lead time required of their noble metal supplies. No schedules compression has been considered as yet.

Even though most catalyst manufacturers could produce both Pellet and Monolith type converters, pellet catalyst are favored by some primarily because of their lower cost, durability and the low cost of replacement which would run between \$20-\$30. For example, Oxy-Catalyst maintains that they would need 0.03 to 0.04 troy ounce of platinum per converter with the pellet type costing approximately \$10 whereas their monolith would run anywhere from \$40-\$50.

Oxy-Catalyst, like other catalyst manufacturers, would require a commitment from auto firms before any new facilities are built. Their schedule lead time for a new plant is 20 months. Sixteen months would be needed for design, engineering and construction; another 4 months for plant shakedown. This schedule is applicable to both pellet and monolith type catalysts and is based on a start date of Sept. 1, 1972; however, a decision with respect to catalyst type must be made by Dec. 1972. Thus, completion would be around May 1974 with a capacity of 15-20 million pounds of Pellet-type catalyst. They could compress their schedule by 3 months with a cost increase of up to 10 percent. If monoliths are the choice, Alco and/or Corning would probably be the supplier with a delivery date of March 1974. Thus, storage would be necessary for a couple of months. However, pellet suppliers lead time would correlate very well.

Though pellets are cheaper, they do not perform as well as monoliths. Matthey-Biship is considering supplying plated monolith-type converters at an estimated cost of \$15-\$18. This includes the substrate, Al_2O_3 wash coat as well as a noble metal coating (0.04 ounce of platinum and a proprietary amount of other non-noble metals). They do not intend to package the converter, but are willing to give aid, without cost, to the canister manufacturer. It has been estimated by Matthey-Bishop that packaging may run from \$0.50 to \$0.60 per unit.

Should Matthey-Bishop get a contract to produce a catalyst, they would need to build a new facility. The lead time would be about 21 months; design and contracting should take 3 months. Construction and installation of equipment is estimated to take 14 months; the remaining 4 months is needed for start-up and shakedown. The new facility would have an output of 1.8 mil. units a year and cost around \$4 million.

Since plant expansion is rather simple, capacity could be further increased, however, notification must be received by April 1973. Orders for substrate would have to be placed before this date. Their lead time correlates very well with American Lava, a potential substrates supplier.

Several catalyst manufacturers are considering producing their own substrate. Universal Oil Product and W. R. Grace Co. are both considering producing pellet substrate and then adding their catalytic material. Grace has the capacity with slight modification to existing equipment to produce 15-20 mil. pounds of pellet substrate a year. Since this would not be enough to supply any one auto firm, they would have to contact outside pellet suppliers.

Grace has already made plans to produce a monolith but as yet has not made any contractual agreements with the auto firms. They may make some agreement with outside monolith suppliers if their monoliths are not accepted.

Following the receipt of a contract or purchase order, Grace would build either a pellet of monolith catalyst plant at a cost of $5-15 million. The scheduled lead time given for the plants are 24 mos. for pellet and 22 mos. for monolith. Engineering and design would cover 3 mos. Construction of the pellet plant is estimated to take 18 months whereas the monolith would take 16 months. The remaining 3 mos. would involve plant shakedown and checkout.

No scheduled compression is possible for their monolith plant; however, the pellet catalyst lead time could be compressed by 3-6 months at a $0.10 - 0.05 per pound cost increase.

Universal Oil Products is considering an output of 5 million units a year regardless of which catalyst is chosen. They prefer a monolith and could supply it at a cost of $10-12. New facilities have already been planned; however, a final decision by G. M. on whether to order pellet or monolith is being awaited before construction beings. There is an estimate of 20 months before shipment could commence which would be around June 1974.

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9. Trip Report - Universal Oil Products, Production Lead-Time Study, 30 August 1972.

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